ACRP SYNTHESIS 5

AIRPORT COOPERATIVE RESEARCH PROGRAM

Airport Ground Access Mode Choice Models

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A Synthesis of Airport Practice

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AIRPORT COOPERATIVE RESEARCH PROGRAM

ACRP SYNTHESIS 5

Airport Ground Access Mode Choice Models

A Synthesis of Airport Practice

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AIRPORT COOPERATIVE RESEARCH PROGRAM

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The ACRP benefits from the cooperation and participation of airport professionals, air carriers, shippers, state and local government officials, equipment and service suppliers, other airport users, and research organizations. Each of these participants has different interests and responsibilities, and each is an integral part of this cooperative research effort.

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FOREWORD

By Staff
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Airport administrators, engineers, and researchers often face problems for which information already exists, either in documented form or as undocumented experience and practice. This information may be fragmented, scattered, and unevaluated. As a consequence, full knowledge of what has been learned about a problem may not be brought to bear on its solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

There is information on nearly every subject of concern to the airport industry. Much of it derives from research or from the work of practitioners faced with problems in their day-to-day work. To provide a systematic means for assembling and evaluating such useful information and to make it available to the entire airport community, the Airport Cooperative Research Program authorized the Transportation Research Board to undertake a continuing project. This project, ACRP Project 11-03, "Synthesis of Information Related to Airport Practices," searches out and synthesizes useful knowledge from all available sources and prepares concise, documented reports on specific topics. Reports from this endeavor constitute an ACRP report series, Synthesis of Airport Practice.

This synthesis series reports on current knowledge and practice, in a compact format, without the detailed directions usually found in handbooks or design manuals. Each report in the series provides a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems.

PREFACE

This synthesis extends previous efforts to document the state of practice for airport ground access mode choice models. It examines the characteristics of existing models and discusses the issues involved in the development and use of such models to improve the understanding and acceptance of their role in airport planning and management. Information presented in this report may be of interest to a range of airport managers, airport and regional transportation planners, consultants and transportation modeling specialists, and researchers interested in issues involving airport ground access mode choice.

For this synthesis, a comprehensive review of the relevant literature was undertaken. To document the extent of the recent use of airport ground access mode choice models and to identify sources of technical documentation on existing models, this literature review was supplemented by a survey of airport authorities, metropolitan planning organizations, consulting firms and research organizations, and other government agencies and industry organizations. Follow-up communications by telephone and e-mail were made where necessary.

Geoffrey D. Gosling, Aviation System Consulting, LLC, Berkeley, California, collected and synthesized the information and wrote the report. The members of the topic panel are acknowledged on the preceding page. This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As progress in research and practice continues, new knowledge will be added to that now at hand.

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AIRPORT GROUND ACCESS MODE CHOICE MODELS

SUMMARY

The prediction of air passenger and airport employee mode choice decisions for travel to and from the airport forms a key analytical component of airport landside planning, as well as airport system planning. However, there is currently no generally accepted and validated approach to modeling how airport users will change their access or egress mode in response to changes in the airport ground transportation system. The factors affecting airport travel are recognized as being significantly different from those affecting typical trips accounted for in regional transportation models. Therefore, it is difficult to determine the economic feasibility of proposed projects to improve airport ground transportation or effectively manage the existing airport ground transportation system using traditional regional models.

Travel forecasting models, particularly those developed to address airport ground access and egress trips, are highly specialized and not well understood by most airport managers and planners. With increasing emphasis on intermodal connections, there is a pressing need for more widely accepted and accessible reference material and information on such models. This report has been undertaken to update and extend previous efforts to document the state of practice for airport ground access mode choice models. It examines the characteristics of existing models and discusses the issues involved in the development and use of such models, as well as research and development efforts that are needed to improve the state of the art of modeling airport ground access mode choice and address technical issues that are not currently well handled.

The synthesis project has undertaken a comprehensive review of the relevant literature in the field. This was supplemented by an extensive survey of airport authorities, metropolitan planning organizations (MPOs), consulting firms and research organizations, and other relevant government agencies to document the extent of the recent use of airport ground access mode choice models and to identify sources of technical information on existing models. Based on the findings of the literature review and survey, the report summarizes the current state of practice of both air passenger and airport employee ground access mode choice models and discusses the type of planning issues to which the models have been applied, the technical approach adopted, the ground access modes included in the models, and the explanatory variables and market segmentation used to account for air passenger ground access behavior. The report also addresses the extent to which air passenger ground access mode choice models may be transferable to situations different from the one for which they have been originally developed and issues that arise in integrating air passenger and airport employee ground access mode choice models into more general regional transportation planning models.

The development of air passenger ground access mode choice models has been the subject of ongoing research for more than 30 years, during which time the state of practice has evolved from relatively simple multinomial logit (MNL) models to more complex nested logit (NL) models involving several levels of nesting and four or more market segments. However, no clear consensus has yet emerged as to what explanatory variables should be included or how the various modes and sub-modes should be nested and a number of problematic issues have not yet been addressed in a meaningful way, including how to treat rental

The overall process of developing an airport access mode choice model is summarized in Figure 1 and discussed in more detail in chapter two of this report.

The basic concept underlying most disaggregate discrete choice analysis is that each alternative in the choice set provides the decision maker with some *utility* that can be expressed in terms of measurable or observable characteristics of both the decision maker and the alternative (e.g., the travel time involved or the income level of the decision maker). The larger the difference in the utility between two alternatives, the more likely the decision maker is to choose the alternative with the higher utility. Because the probability of choosing a particular alternative cannot be greater than one or less than zero, this results in an S-shaped relationship between the difference in utility between two alternatives and the probability of choosing the alternative with the greater utility for that decision maker. A common mathematical form for this relationship is the *logistic function*, which for more than two alternatives results in the MNL model that has been widely used for airport access mode choice studies. This model can be expressed as:

$$P(i) = \frac{e^{U_i}}{\sum_{j \in J} e^{U_j}}$$

where $P(i)$ is the probability of a decision maker choosing alternative i, U_i and U_j are the utilities of alternatives i and j, and J is the number of alternatives. The *utility function* for a given alternative is assumed to comprise a *deterministic* part that consists of a function of measured and observed variables and an *error* term that accounts for unobserved characteristics and variability in the perceived utility of a given set of characteristics across different individuals. In logit choice models, the error term is assumed to be a random variable and the variance of the error term reflects the goodness-of-fit of the model. The deterministic part of the utility function typically consists of a linear combination of explanatory variables with their associated model coefficients, the values of which are determined in the model estimation process. Therefore, a utility function can be expressed as:

$$U_i = a_i + b_1x_1 + b_2x_2 + \ldots + b_nx_n + \varepsilon$$

where a_i and the b's are the model coefficients, the x's are the values of the explanatory variables such as travel time and cost, and ε is the error term. In general, the utility function for each alternative will have a constant term a_i, known as the *alternative-specific constant,* which reflects attributes of the alternative that are not accounted for by the other variables. Therefore, a fairly simple utility function for a mode choice model might comprise:

$$V_i = a_i + b_1(\text{travel time}) + b_2(\text{waiting time}) + b_3(\text{walk distance}) + b_4(\text{cost/income})$$

where V_i is the deterministic part of the utility function (it is common to omit the error term in presenting the components of a utility function). In this example, travel cost is divided by income in the fourth explanatory variable so that the choice process becomes less sensitive to cost for higher-income travelers.

Although the MNL model has been widely used, it is vulnerable to problems that arise from a property of the model termed the Independence from Irrelevant Alternatives. This states that including a new alternative in the choice set (or changing the perceived value of one of the alternatives) should not affect the relative probabilities of choosing any of the other alternatives. However, in many situations in airport access mode choice it is quite unlikely that changing the characteristics of one mode or sub-mode will leave the relative probabilities of choosing all the other modes and sub-modes unchanged. For example, changes in one public transportation service are likely to affect the use of other public transportation services to a greater extent than the use of private vehicles. These limitations can be addressed by

grouping similar modes or sub-modes into separate groups or *nests* in a choice structure referred to as a NL model, as illustrated by Figure 4 in chapter three.

This figure (from a ridership study for a proposed airport express train in Chicago) shows that private transport modes have been grouped together in one nest, whereas public transport modes have been grouped in a different nest. It also shows another feature of NL models, that it is possible to define lower-level nests that contain sub-modes of a particular mode, in this case the access mode by which travelers reach the airport express train. The grouping of modes in the NL model requires some changes to the mathematical form of the model, which are not discussed here but are described in chapter two.

Once a calibrated or validated model is available, the process of applying the model is technically fairly straightforward, although there are a number of aspects that need to be carefully considered in developing the required input data and interpreting the results. One is that although a relatively small survey sample size (a few thousand respondents in the case of air passengers and perhaps even fewer for airport employees) may be adequate to estimate an airport access mode choice model, a much larger sample may be required for a given application of the model, depending on the issues of interest and the desired level of geographic resolution of the results. Two other considerations involve how to adjust the model to be able to predict behavior in future years, as is typically needed for planning studies. The first of these is how to adjust travel times and, particularly, costs to correspond to future conditions. These adjustments will need to consider expected changes in highway congestion as well as anticipated changes in real costs (in constant dollars) over time. The second consideration involves adjustments for the effect of changes in the levels of real household incomes over time. Implicit in the calibrated coefficients of a mode choice model are assumptions about how travelers trade off time and cost. If real incomes change, these tradeoffs can be expected to change as well. These issues are discussed in more detail in chapter two.

- **Review of Literature**

Given the importance of understanding air passenger airport ground access mode use it is not surprising that there have been a number of studies over the years that have developed air passenger ground access mode choice models. One of the earliest efforts to develop a formal model of air passenger airport ground access mode choice was undertaken by Ellis et al. in the early 1970s. This study used a MNL model, as did several other studies that developed air passenger ground access mode choice models over the next ten years. However, by the mid-1980s, it was becoming recognized that some of the limitations of the MNL model could be addressed through the use of NL models. One of the first applications of NL models to airport ground access mode choice was undertaken as part of a study of surface access to London Heathrow Airport, followed shortly thereafter by another study that used a NL structure to develop an integrated model of airport choice and ground access mode choice for the San Francisco Bay Area. Subsequent air passenger ground access mode choice models developed for Boston, Massachusetts; Portland, Oregon; and airports in the southeast and east of England used a nested structure, whereas other studies continued to use MNL models to represent air passenger ground access mode choice. In addition to models that have exclusively addressed airport access mode choice, a number of recent studies have used NL models to represent air passenger airport choice, with airport ground access mode choice as a lower level nest. However, these models generally only include a single-level nest for the airport ground access mode choice process and thus are equivalent to MNL models from the perspective of ground access mode choice.

In addition to papers in the open literature, the synthesis project identified several studies that had developed airport access mode choice models, the details of which had not been widely reported, in several cases because the models had been documented in technical reports that had restricted distribution or did not obviously involve airport access mode choice. These included the regional travel demand model for the Atlanta region, a ridership

forecasting study for a proposed airport express train serving the two Chicago airports, a travel demand forecast study for the planned Miami Intermodal Center, a ridership analysis of a planned automated people mover connection between Oakland International Airport and the nearby Coliseum station of the Bay Area Rapid Transit system, and a revenue and ridership forecasting study for a proposed Air Rail Link between Toronto Union Station and Lester B. Pearson International Airport.

- **Use of Airport Ground Access Models in Airport Planning**

To better understand the current state of practice with airport access mode choice models, as well as to identify models that may have been developed for specific studies but not reported in the published literature, a web-based survey was undertaken of airport authorities, regional and state planning agencies, federal agencies involved in airport or surface transportation planning, airport consulting firms, selected universities and other research organizations, and relevant industry associations. The survey inquired about recent airport ground transportation studies undertaken by the responding organization and whether these involved the use of formal models of airport ground access mode choice. The survey also inquired about respondents' perceptions of the usability of such a model, as well as their awareness of other organizations that have experience with the use of these models.

Survey responses were obtained from 105 different organizations. These responses identified 85 specific studies completed in the past ten years that had included some analysis for airport access mode choice, of which 52 had involved the use of mode choice models. However, only four of these studies were available on the organization's website. The survey also asked about prior experience with airport access mode choice models, and from these responses it does not appear that there has been a significant increase in the use of analytical models in recent years. Respondents who reported the use of analytical models of airport access mode choice were asked to characterize the current state of practice with these models. Approximately 55% indicated that current models were adequate for their needs, 35% reported that current models are not reliable enough, 30% noted that they are too costly to use, and 10% indicated that they are too complex to use. However, it is worth noting that only 5 of the 13 consulting firms reporting involvement in studies using such models indicated that current models are adequate, whereas 7 of the 8 airport authorities and all 5 of the MPOs reporting the use of such models indicated that current models are adequate for their needs. Because in many cases the actual modeling is done by consultants rather than by airport authority or MPO staff, the limitations of the current models may not be fully appreciated by the organization sponsoring the studies.

The survey also explored how airport trips were modeled in the regional travel modeling process. Of the 23 MPOs responding to the survey, 15 (65%) reported using a special-generator sub-model for air passenger trips, whereas about 50% reported using a special-generator sub-model for airport employee trips. The other MPOs either treated airport trips the same way as other regional trips or did not consider airport trips at all.

- **Air Passenger Mode Choice Models**

Although the details of the different air passenger airport access mode choice models identified in the literature review vary widely, it is clear that a standard of best practice has evolved, although by no means is it always followed. This standard of best practice uses NL choice models with separate coefficients (and possibly including different variables) for at least four market segments:

- Resident business trips,
- Resident non-business trips,
- Non-resident business trips, and
- Non-resident non-business trips.

The modes available for resident and non-resident trips will generally be different because non-residents do not have the option of parking a private vehicle at the airport (indeed this would make no sense because their visit to the region begins at the airport and they return to the airport at the end of their stay). On the other hand, many non-residents rent a car on their arrival at the airport to provide local transportation during their stay in the region.

Although no generally accepted practice has yet emerged for how to structure the nests of a NL model, this should largely be determined by the characteristics of the different modes because the primary purpose of using a NL model is to allow higher rates of substitution between modes that have similar characteristics. Therefore, it would appear logical to group private vehicle modes in one nest, with different parking options as a second-level nest, group exclusive ride on-demand modes (taxi and limousine) together in a second first-level nest, and group shared-ride scheduled modes (public transit and scheduled airport bus) together in a third first-level nest, possibly with different transit options (e.g., rail and bus) as a second-level nest. It is not clear where door-to-door shared-ride van should best fit in this structure, as a separate mode at the top level, in the on-demand nest with taxi and limousine, or in the shared-ride nest with the scheduled modes. This may be an issue to resolve empirically by exploring which option gives the best fit to the data. Alternative access modes to scheduled services can also be included as lower-level nests to each mode.

Rental car and hotel shuttle use by non-residents is best modeled outside this choice process, because use of both modes is determined by factors that are largely independent of the service levels of other modes. Rental car use is often determined by local travel needs other than the airport egress and access trips. Therefore, visitors to the region may rent a car even if they are staying at a nearby hotel that has a free shuttle to and from the airport.

The form of the utility functions for each choice alternative will generally be a linear combination of explanatory variables with their associated coefficients. However, some variables are best entered in the utility function as an inverse or ratio. For example, the service headway of scheduled modes, which is a direct measure of average waiting time, is the inverse of the service frequency. The effect of household income may best be entered in the utility function by expressing direct travel costs as a ratio of the cost to some function of the per capita or total household income. Thus, higher-income travelers will be less influenced by cost than lower-income travelers.

- **Airport Employee Mode Choice**

Airport employee ground access and egress mode choice has received much less attention in the literature than that of air passengers, and only three studies were identified that describe an airport access mode choice model developed to account for airport employee access mode choice behavior. These three models each adapted other journey-to-work mode choice models to predict airport employee mode use rather than developing an entirely new model from airport employee travel data.

A special-purpose airport employee mode choice model was developed for the Greater London region as part of the U.K. South East and South of England Regional Air Service (SERAS) Study. This model was a fairly simple binary (two-mode) logit model that predicted the percentage use of private vehicle and public transport and was based directly on one developed for the South and West London Transport Conference for a study covering the area to the south and west of London Heathrow Airport that was felt to provide a good basis for the SERAS work. A study of the potential ridership on a proposed automated people mover link between Oakland International Airport and a nearby rail transit station and a second study of a similar link between San Jose International Airport and a nearby light-rail stop) both used a similar approach of adopting model coefficients from regional travel demand

models for home-based work trips and then estimating alternative specific constants to calibrate the model predictions to survey data on airport employee travel.

The most common way to model employee travel to and from airports is to treat the airport in exactly the same way as any other transportation analysis zone in the regional travel demand model and use the trip generation, trip distribution, and mode choice sub-models for home-based work trips to generate the number of person and vehicle trips associated with airport employee travel. Those MPOs using special-generator models for airport employee travel tailor this process to better fit the number of airport employee trips, typically through the use of airport employment data and surveys of airport employee travel.

- **Transferability of Airport Ground Access Mode Choice Models**

Given the considerable cost and effort required to develop models of airport ground access mode choice, it is natural to ask whether separate models need to be developed for every airport or whether it would be possible to adapt or apply a model developed for one airport for use at another. Indeed, several of the existing models described in this report did just that. In general, experience in applying models of transportation behavior in situations that are different from the one for which they were developed has not been very encouraging. However, this experience has largely focused on models of general urban travel behavior, and airport ground access travel behavior may be more consistent.

In principle, one would expect that air travelers would behave similarly when faced with a similar choice situation, controlling for differences in ground access service characteristics (e.g., fares or travel times) and differences in traveler characteristics (e.g., trip purpose and duration, household composition, and income). Therefore, to the extent that a model accurately reflects the effect of these variables, it should explain the behavior of air parties in other geographical regions. However, this is a significant caveat, because many models are heavily dependent on alternative specific constants that at best reflect a range of local factors that are not explicitly included in the model and at worst correct for problems in the model specification. In particular, there may be regional differences in attitudes toward the service characteristics of different modes as well as differences in the nature of the services offered.

One important consideration is the way in which different modes are included in NL models. Because the nesting structure of the limited number of models that have used a NL structure is very dependent on the particular modes that exist in the region being modeled, it is difficult to generalize about how the various models have grouped the modes. It is unclear whether differences in the nesting structure of different modes reflects fundamental differences in choice behavior across different regions is a consequence of the modes included in the models or the explanatory variables used, or merely reflects different modeling philosophies by different developers. The way in which household income is included (or not included) in the models will also affect how well they can be expected to explain behavior in other regions where the distribution of household incomes is different.

Given the current lack of consensus over model specification and typical coefficient values between different airport access mode choice models, it can be assumed that the transferability of these models is highly suspect. Although it seems plausible that the underlying airport traveler behavior may not differ that much from region to region, after taking into account differences in air passenger or airport employee characteristics and transportation system service levels, it appears unlikely that current airport access mode choice models do this in a way that is transferable to other regions, based on the significant differences between the different models. There is an urgent need to better understand how well current models reflect the factors influencing the underlying travel behavior and how they can be improved to better reflect this behavior, both because of the obvious value of being able to apply airport access mode choice models in different situations from those for which they were originally developed, as well as

the concerns about the reliability of even applying them to different situations at the airports for which they were developed.

- **Airport Ground Access Models in the Regional Planning Process**

Although modeling airport access mode choice by air passengers and, to a lesser extent, airport employees, has largely been restricted to specialized studies addressing airport land-side and system planning issues, there is a growing interest in explicitly modeling such trips in the regional transportation planning process. A number of MPOs have begun to address air passenger trips using a special-purpose mode choice model or special-generator sub-model and a somewhat smaller number of MPOs have begun to do the same for airport employee trips. However, the majority continues to model trips to and from airports as regular regional travel using a standard trip classification such as home-based non-work trips. Because these standard trip classifications encompass a very wide range of activities, most of which have very little in common with airport travel, it would be surprising if the model components did a very good job of predicting airport access mode choice.

This is compounded by the concept that air passengers in particular typically have access to a much larger number of alternative modes for airport access and egress trips than are usually modeled in regional travel demand models, including taxi and limousine services, shared-ride door-to-door van services, and scheduled airport express bus services. Furthermore, a significant fraction of all airport access and egress trips is made by visitors to the region. Most current regional travel models are only designed to model travel by residents of the region and largely ignore travel by visitors. Therefore, modes such as rental car and hotel courtesy shuttle are typically not included in the models. Finally, the largest single air passenger access or egress mode at many airports, for both visitors and residents, is being dropped off or picked up by private vehicle. This option is also typically not explicitly modeled in regional travel models. Models predicting private vehicle use that are based on the assumption that the vehicle will be parked at the destination until the return trip will thus underestimate the vehicle-miles of travel involved by a factor of two.

These concerns may not be particularly important in terms of total regional travel, because airport trips comprise a fairly small fraction of all regional trips. However, these issues become of much greater concern when the regional travel models are used to predict trips on parts of the transportation network in the vicinity of the airport or are used for airport access and egress studies, including predictions of airport access and egress trips for use in environmental impact studies. Therefore, a fairly strong case can be made that airport access and egress trips need to be modeled separately from general regional travel patterns (or at least as a special-generator sub-model within the overall modeling framework) and then integrated with other trips in the traffic assignment process.

This synthesis project examined some of the technical issues involved in modeling airport trips within the context of regional travel demand models and identified a range of approaches that has been followed by different MPOs that have explicitly modeled airport trips in their regional travel modeling process. These approaches vary from a special-purpose sub-model within the travel modeling process of the Atlanta Regional Commission, through the external generation of airport trip tables that are combined with the trip tables generated by the regular travel modeling process of the Metropolitan Washington Council of Governments, to two examples of the use of external airport access mode choice models. In the case of the Boston Central Transportation Planning Staff, an air passenger mode choice model was developed in-house in cooperation with the airport authority. In contrast, the Southern California Association of Governments uses a proprietary air passenger mode choice model, the output of which is then used as input to the regular regional travel modeling process. Further information on these four approaches is provided in chapter eight of this report.

- **Conclusions and Further Research**

Airport ground access and egress mode choice models play a critical role in airport landside planning studies and modeling traffic on the regional transportation system in the vicinity of airports. The ability to predict how air passenger and airport employee access and egress mode use will change in response to changes in the airport landside access system or other anticipated changes in the regional transportation system is essential to the proper evaluation of proposed measures and projects. However, these decisions are influenced by very different factors from those affecting general regional travel patterns and the transportation options available to airport travelers are often quite different from those for other types of regional trip. Therefore, there is a need for specialized models that can represent these mode choice decisions as well as the means to integrate these models or their output into the regional traveling modeling process.

The development of air passenger ground access mode choice models has been the subject of ongoing research for more than 30 years. Over this period, the state of practice has slowly evolved from relatively simple MNL models to more complex NL models involving several levels of nesting and four or more market segments. However, no clear consensus has yet emerged as to what explanatory variables should be included or how the various modes and sub-modes should be nested. In addition, even the most recent models have still not addressed a number of problematic issues in a meaningful way. These include how to treat rental car use by non-residents of a region and how best to account for the role of traveler income in the mode choice process. Aside from these technical considerations, there has been almost no attention given to how reliably existing models predict air passenger access mode use when they are used to predict mode use under very different conditions from those prevailing when they were developed, including changes in the physical infrastructure, ground transportation services, and household income levels. There is an urgent need for more research into these specific aspects, as well as continuing research directed at improving the current state of practice.

In contrast to air passenger mode choice models, there has been very little effort directed at developing airport employee mode choice models. The majority of MPOs model airport employee trips the same way as they model any other journey-to-work trips. The development of better airport employee access models is a promising research opportunity.

Finally, many existing regional travel models do not explicitly model airport trips, but treat them as general regional travel. Because of the unique characteristics of airport travel and the range of transportation options typically available at airports, this is likely to give fairly poor predictions of airport mode use and the resulting vehicle trips. Further research is needed to explore how well existing regional travel models account for airport trips and to provide guidance on how best to implement explicit modeling of airport access mode choice in the regional travel modeling process.

CHAPTER ONE

INTRODUCTION

BACKGROUND

The prediction of air passenger and airport employee mode choice decisions for their travel to and from the airport forms a key analytical component of airport landside planning, as well as airport system planning. There is currently however no well-accepted and validated process for modeling how airport users will change their access or egress mode in response to changes in the airport ground transportation system (such as changes in fares, rates, or service levels) or the introduction of new modes (such as the extension of a light rail system to the airport). The factors affecting airport travel are recognized as being significantly different from those affecting typical trips accounted for in regional transportation models, as a result of both the characteristics of the travel party and the timing and duration of the trip, as well as the differences in available modes and services. Therefore, it is difficult to determine the economic feasibility of proposed projects to improve airport ground transportation or effectively manage the existing airport ground transportation system using traditional regional models.

Travel forecasting models, particularly those developed to address airport ground access and egress trips, are highly specialized and not well understood by most airport managers and planners. With increasing emphasis on intermodal connections, there is a pressing need for more widely accepted and accessible reference material and information on such models. This synthesis project was undertaken to update and extend previous efforts to document the state of practice for airport ground access mode choice models. It also examines the characteristics of existing models and discusses the issues involved in the development and use of such models to improve the understanding and acceptance of their role in airport planning and management. It is hoped that the report will also serve to focus research and development efforts on improving the state of the art of modeling airport ground access mode choice by assembling a detailed database of comparative information on recent model development efforts and identifying technical issues that are not currently well handled.

In contrast to the current state of practice of urban transportation modeling, which has been the subject of study and improvement by a large body of practitioners and researchers for many decades, airport ground access mode choice modeling has received only limited attention and relatively little funding. As a result, no clearly recognized body or practice has emerged and relatively few people have worked in this area long enough to develop significant expertise. Typically, airport access mode choice models have been developed by transportation modeling specialists, airport planners, or academic researchers who are mainly concerned with other issues. Part of the reason for this is that opportunities to develop such models occur relatively infrequently. At the same time, modeling airport ground access mode choice is arguably more complicated and challenging than general urban travel. First, airport ground access usually involves more transportation modes than are typically considered in general urban travel demand models, which are commonly restricted to single-occupant automobiles, carpools and vanpools with varying occupancy levels, and conventional transit services. The airport ground access system includes all of these, as well as other modes that are rarely considered in general urban travel models, such as rental car, taxi, shared-ride van, dedicated express bus services, and hotel courtesy shuttles, all of which can have a significant mode share at large airports. Indeed, at many airports the rental car is the largest single mode after private vehicles, and the other shared-ride transportation modes typically carry more passengers than transit.

Second, the circumstances surrounding airport access trips by air passengers are very different from other types of urban travel. A high proportion of travel is by visitors to the region; passengers travel in groups more often than for other urban trips, they make airport access trips far less frequently than other urban trips, they commonly have luggage, and they are often away for several days or even several weeks, which affects the cost and feasibility of parking a car at the airport while they are away. Picking up and dropping off air passengers at the airport with a private vehicle is one of the most common access and egress modes. This generates twice as many vehicle trips to and from the airport as air party trips owing to the round trip involved in either dropping off or picking up air travelers. These factors greatly complicate the issues that need to be considered in developing airport access mode choice models.

METHODOLOGY

A comprehensive review of the relevant literature in the field was undertaken. This was supplemented by an extensive survey of airport authorities, metropolitan planning

organizations (MPOs), consulting firms and research organizations, and other government agencies and industry organizations to document the extent of the recent use of airport ground access mode choice models and to identify sources of technical information on existing models. Based on the responses to the survey, technical documentation on existing models has been assembled and reviewed, supplemented with follow-up communication by telephone and e-mail where necessary. The findings of this review were then assembled into a project database that was used to prepare summary descriptions of each model in a standard format.

The survey of airport authorities and other organizations was undertaken to complement the review of published literature as well as to obtain information on the extent to which each organization makes use of formal models of airport access travel and perceives the ease of use or reliability of such models. The survey was undertaken using Internet survey software hosted on the TRB website. E-mails were sent to survey recipients requesting their participation and providing a link to the appropriate survey. Four somewhat different survey questionnaires were developed reflecting the different concerns and needs of the various types of organizations included in the survey. Survey recipients were given the option of responding using a form that could be completed off-line and returned by e-mail, fax, or mail.

POTENTIAL USES OF AIRPORT ACCESS MODE CHOICE MODELS

Airport access mode choice decisions by airport travelers, including both air passengers and airport employees, impact a wide range of airport planning and operational management decisions, including the development of landside facilities, airport revenue from parking and other ground transportation services, and programs to reduce the growth in vehicle trips generated by the airport and the associated emissions. Potential uses of models that can predict the effect on access mode use of proposed changes to the system include sizing new planned facilities, evaluating the financial implications of proposed changes in parking rates or other ground transportation fees, determining the expected air quality impacts of either planned new facilities or proposed mitigation measures, and assessing the feasibility of proposed projects to improve airport access. Airport accessibility is also a major determinant of airport choice in multi-airport regions or situations where air service competition exists between local and more distant airports. Airport access mode choice is often embedded within models of airport choice, because the availability and use of different access modes affects the perceived accessibility of different airports, and improved representation of airport access mode choice behavior should benefit those applications as well. Several of these potential applications are discussed in more detail in chapter two.

REPORT AUDIENCE

The information presented in this report may be of interest to a range of airport managers and planners, transportation planning professionals, researchers, and others interested in modeling airport ground access mode choice. *Airport managers* may be interested in obtaining a fairly high-level understanding of the current state of practice and an appreciation of where and how such models can be used, as well as what is involved in using them. Such readers may find the executive summary sufficient or they may prefer to go into more detail in selected sections of the report, particularly the description of the mode choice modeling process in chapter two. *Airport planners* and *regional transportation planners* who are more directly involved in airport landside planning or regional travel demand modeling but do not have extensive experience with airport access mode choice modeling may find the description of the mode choice modeling process in chapter two of interest, as well as the technical details of existing models in the following chapters. Regional transportation planners may find the discussion of the role of airport ground access mode choice modeling in the regional travel demand modeling process in chapter eight of particular interest. *Consultants* and *transportation modeling specialists* who have prior experience with airport access mode choice models may find the comparative discussion of the various existing models of interest, together with the review of their strengths and weaknesses contained in the detailed case studies in Appendix D (which is found in the online version only). Finally, *researchers* interested in issues involving airport ground access mode choice may be interested in the discussion of the aspects of the current state of practice that are not well understood and the associated suggestions for future research in this topic that appear throughout the report.

REPORT ORGANIZATION

The remainder of this report consists of eight chapters and four appendixes. Chapter two describes the airport access mode choice modeling process and discusses a range of issues that arise in modeling airport access mode choice. Chapter three reviews the published literature on air passenger airport access mode choice models and addresses airport employee mode choice for journey-to-work trips. Chapter four reviews the use of airport ground access mode choice models in airport planning based on the findings of the survey of airport authorities, regional and state planning agencies, and other organizations. The chapter examines the extent to which formal models of air passenger or airport employee ground access mode choice have been used in airport planning studies, as well as how airport access trips are addressed in regional transportation planning models.

Chapter five presents the current state of practice of air passenger ground access mode choice models and forms the core of this synthesis review. The chapter discusses the type

of planning issues to which the models have been applied, the technical approach adopted to represent air passenger choice behavior, the ground access modes included in the models, the explanatory variables used to model the transportation system and air passenger characteristics, and the market segmentation that has been used to improve the ability of the models to account for air passenger ground access behavior. It also discusses a number of considerations that arise in developing and applying these models, as well as issues of model performance.

Chapter six reviews the corresponding state of practice with the analysis of airport employee journey-to-work travel. In contrast to air passenger ground access, the literature review and survey of airport authorities and other organizations identified relatively few formal mode choice models explicitly developed to represent airport employee journey-to-work travel. Rather, analysis of airport employee travel in airport planning studies tends to be based on extrapolation from survey data of existing travel patterns, although regional planning studies typically use models designed for general urban travel.

The next two chapters explore two issues that arise from the review of current practice described in the previous chapters. Chapter seven addresses the extent to which air passenger ground access mode choice models may be transferable to situations different from the one for which they have been originally developed, or whether it is necessary to custom build ground access mode choice models for every airport. Chapter eight discusses the issues that arise in integrating air passenger and airport employee ground access mode choice models into more general regional transportation planning models.

Finally, chapter nine presents the conclusions of the synthesis of current practice and recommendations for further research. These address needed improvements in the current state of practice for air passenger ground access mode choice models as well as the development of appropriate models for airport employee mode choice for journey-to-work trips.

The four appendixes provide more detailed information as background to the discussion in the body of the report. Appendix A presents the questionnaires used in the surveys of airport authorities, planning agencies, and other organizations; Appendix B contains a detailed summary of the survey findings; Appendix C lists the organizations that responded to the survey; and Appendix D (provided only online) contains detailed technical summaries of nine of the mode choice models identified in the project.

CHAPTER TWO

AIRPORT GROUND ACCESS MODE CHOICE MODELING PROCESS

This chapter provides a short introduction to the motivation and methodology for modeling airport ground access mode choice. It is primarily intended to give airport management and planning staff some background on how these models can be used in the planning and decision-making process, and provide an overview of the technical issues involved in developing and applying these models so that they can interact with more technical specialists in an informed way and properly supervise contracts for the development and use of such models. It is also hoped that it will be helpful to airport planning consultants and other planning specialists, including transportation planners working for MPOs and other planning agencies, who do not have particular expertise in airport ground access modeling, but become involved in airport ground access modeling issues.

As will be apparent from the detailed discussion in this report, airport ground access mode choice modeling is a highly specialized field, with many complex aspects that make this a particularly challenging problem. This has two implications. The first is that the development of these models typically requires the use of specialists with prior experience in modeling airport ground access mode choice. The second is that it is therefore helpful if other planners and managers involved in the larger planning process have some idea of what is involved in developing and using these models, so that they have appropriate expectations of both the resources required and what it is reasonable to be able to accomplish with a given level of resources.

MOTIVATION FOR MODELING AIRPORT GROUND ACCESS MODE CHOICE

Airport travelers make use of a wide variety of different modes for their ground access trips to and from the airport, including private vehicles, rental vehicles, taxis, and multiple private and public transportation services. Large airports in particular are served by a large number of different ground transportation modes and services. Planning landside and airport ground access facilities, as well as accounting for the environmental impacts of airport ground transportation activities, requires the ability to predict how airport users will change their ground access and egress decisions in response to changes in the array of options that they face. It would be impractical to imagine that the proportion of airport users choosing a particular mode will remain constant when the factors influencing their choices are continuously changing.

In some cases, an airport may want to understand the consequence of decisions that are largely outside its control, such as changes in the price or service pattern of ground transportation services operated by other entities or changing congestion levels on the regional transportation system. In other cases, it may want to understand how decisions that it is considering will affect the airport ground transportation system or be affected by it. Examples of such decisions could include proposed changes in parking rates for airport-operated parking lots, the introduction of a shuttle bus link to a nearby rail station, or the construction of a consolidated rental car facility some distance from the airport terminal. Each of these decisions is likely to result in changes in the relative attractiveness of the different access and egress modes (including the different on-airport and off-airport parking facilities) and resulting shifts in the proportion of airport travelers using each mode, as well as the effect of this on the revenue generated by each facility or service. Finally, the requirement to predict the environmental impacts of decisions that change or affect the airport ground transportation system, particularly the need to predict air quality impacts, demands an ability to assess how those decisions will affect the use of the various modes (Gosling 2005). This can be a particularly critical issue for airports in regions that are not in attainment of the National Ambient Air Quality Standards, where it may be necessary to be able to demonstrate that a proposed project will not increase total emissions or that appropriate mitigation measures will offset any increase in emissions from the project. Indeed, it may be necessary to be able to demonstrate a reduction in total emissions.

Prediction of how changes in the airport ground transportation system will influence the mode choice decisions of airport travelers is complicated because those decisions depend not only on the price and level of service of the alternative modes but also on the characteristics of the individual travelers. In the case of air passengers, these characteristics include their trip purpose, whether they are residents of the region or visitors to it, how long residents of the region will be away from home on their trip, and whether visitors to the region will need a rental car for local travel during their visit. The distribution of these characteristics across the population of airport travelers not only varies seasonally but also in response to external influences, such as currency exchange rates and the state of the regional economy, and changes in the air services offered at the airport.

Given the many different factors influencing the proportion of airport travelers using each mode, it is unrealistic to expect planners and decision makers to be able to make quantitative estimates of the effect on mode use of any given change in the system without the use of formal analytical tools that model how airport users respond to changes in the available airport ground transportation services. Thus, airport ground access mode choice models provide the basic input to other analysis tools that are used to support airport landside and ground access planning and decision making, such as traffic flow models, simulation models, or financial planning tools.

Representative Applications

To illustrate the type of decision that can benefit from the availability of an airport access mode choice model, this section describes three representative situations where such a model could be applied.

Airport A is experiencing steady growth in air traffic and is planning to construct a new passenger terminal alongside the existing terminal. The existing surface parking lot in front of the current terminal is already reaching capacity at peak periods and there is no space between the terminal roadways and the site of the new terminal to significantly expand the parking lot. The terminal redevelopment plan envisages constructing a multi-level parking structure on the site of the existing surface lot. To pay for the parking structure, the airport authority is considering raising the daily parking rate once the new structure is in operation. However, it is concerned that this will reduce the parking demand for the new structure and divert air passengers to the surface long-term parking lot some distance away, privately operated off-airport parking facilities, or even convince some air passengers who might otherwise park at the airport to be dropped off and picked up instead, or make use of other modes such as a shared-ride van. It recognizes that the extent of any such diversion will depend on the new rate charged for the parking structure, any change in the rate for the use of the long-term lot, and whether the off-airport parking lot operators also adjust their rates. To study the effect of different rate structures on the demand for parking at both the new parking structure and the long-term lot, and the implications for the financial feasibility of the new parking structure, the airport retains a consultant to develop an airport access mode choice model that can be used to analyze the impact of different rate structures on parking demand and identify the optimal pricing strategy and resulting parking demand in both facilities.

Airport B is in a non-attainment region for several ambient air quality standards and is under pressure from the local Air Resources Board to reduce the emissions from airport ground access and egress travel. The airport authority recognizes that unless it can show significant progress at reducing emissions, it is unlikely to be able to undertake a much-needed terminal modernization and expansion program. The airport planning staff has suggested that as part of the terminal modernization program the airport construct an automated people mover (APM) link to the nearest station on the regional light-rail system, located approximately one mile from the airport, to replace the existing infrequent transit bus service between the airport and the light rail system. However, there are concerns about the capital and operating cost of the proposed people mover link and the likely use it will attract. As part of the landside planning for the modernization program, the airport decides to undertake a feasibility study of the APM link in cooperation with the regional transit authority. The scope of work for the feasibility study includes the development of a ground access mode choice model that can be used to evaluate the likely increase in the use of the light rail system for airport trips if the APM is constructed, as well as explore alternatives such as an enhanced shuttle bus connection to the light rail system or an express bus service to several off-airport terminals with remote parking.

The MPO for the region served by Airport C has recognized for some time that its regional travel demand model significantly underestimates vehicle trips to and from the airport when compared with the vehicle traffic volumes projected in landside planning studies undertaken by the airport authority and environmental documentation prepared for airport projects. A detailed review of the travel demand model and discussions with airport planning staff reveal that the underestimate is the result of two factors. The first is that the standard trip generation and attraction relationships in the model substantially underestimate the number of air passenger trips to and from the airport owing to the absence of relevant variables in the model and that the modeling process does not explicitly consider visitor trips to the region. Second, the mode choice model in the overall modeling process underestimates vehicle trips and produces poor estimates of the traffic composition by not accounting for several key characteristics of airport ground access and egress travel. These issues include not accounting for the two-way trips by private vehicles picking up or dropping off air passengers, underestimating the proportion of shared-ride automobile trips by ignoring that many air travel parties have more than one person, and those dropped off or picked up by private vehicles necessarily involve a shared-ride trip in one direction, not considering taxi and limousine trips, and treating vehicle trips by public modes such as a shared-ride van as part of regular public transit use.

To improve the ability of the regional travel demand model to estimate airport trips the MPO decides to develop a special-generator sub-model for airport access and egress trips. This sub-model combines a trip generation module and a mode choice module and generates vehicle trip tables for each category of vehicle trips included in the regional model that are combined with the trip tables for general regional travel before the traffic assignment stage of the regional

model. The trip generation module converts airport passenger traffic forecasts into estimates of person-trips between the airport and each regional travel analysis zone, whereas the mode choice module converts these estimated person-trips into the corresponding vehicle trips for use in the regional travel demand model.

Airport Choice

The need to model air traveler choice of airport in multi-airport regions or situations where air service competition exists between local and more distant airports is becoming increasingly prevalent in airport system planning studies, particularly as low-fare carriers introduce service at secondary airports often some distance from congested major hubs. It is recognized that airport accessibility is a major determinant of airport choice, because the availability and use of different access modes affects the perceived accessibility of different airports. In consequence, the airport access mode choice process is often embedded within models of airport choice and improved representation of airport access mode choice behavior should benefit those applications as well.

OVERALL MODE CHOICE MODEL DEVELOPMENT PROCESS

This section presents an overview of the process of developing an airport access mode choice model. The application of such a model to support planning or decision-making activities is discussed in a subsequent section. In broad terms, the general approach to developing a mode choice model is no different from the development of any other mathematical model of a physical or behavioral process. A set of data is assembled that describes the process being modeled. Then, a suitable functional form for the mathematical model is defined that expresses the value of the variable that the model is intended to predict in terms of some other explanatory variables and model coefficients (sometimes referred to as parameters), the values of which are to be determined from the data. Statistical model estimation software is then used to estimate the values of model coefficients that best explain the observed values of the variable that the model is intended to predict, termed the *dependent variable*, using the observed values of the explanatory variables, termed the *independent variables*. The extent to which the model is able to reproduce the observed values of the dependent variable for any given set of values of the independent variables is referred to as the *goodness-of-fit* of the model and is an important measure of the usefulness of the model.

As with most model development efforts, the process is usually iterative. An initial functional form for the model is proposed. The values of the model coefficients are estimated and the fit of the model to the data examined. Then, based on how well the model appears to fit the estimation dataset and the reasonableness of the estimated coefficient values, the functional form is modified and new coefficients are estimated, hopefully improving the fit of the model. The process continues until a satisfactory model is obtained. Changes to the functional form of the model that are typically explored include adding or dropping independent variables, changing the way that an independent variable is defined or appears in the model, or segmenting the data so that different coefficient values are obtained for different subsets of the data, or different independent variables or model functional forms are used for different subsets of the data (e.g., developing separate models for business and non-business travel).

In the case of airport access mode choice models, there are two types of data that are required to estimate a model. The first type of data consists of the access mode choices made by a representative sample of airport users, together with explanatory data about their characteristics (such as their household income) or the characteristics of their trip (such as where they commenced their journey to the airport or the purpose of their air trip). These data are typically obtained from surveys of air passengers or airport employees, as the case may be. The second type of data consists of the transportation characteristics (such as travel time and cost) of the various access modes between which the mode choice decision was made. Because the mode choice decision depends not only on the transportation characteristics of the mode actually chosen, but also on the characteristics of the modes that were not chosen, it is generally necessary to obtain the transportation characteristics for all the modes included in the model corresponding to each airport user included in the estimation dataset. This can be a significant amount of work and is discussed further later.

The overall process of developing an airport access mode choice model is summarized in Figure 1 and discussed in more detail in the following sections.

Aggregate Versus Disaggregate Models

There are two broad types of behavioral models such as a transportation mode choice model. An *aggregate* model attempts to predict the value of an attribute of a group of decision makers, such as the percentage of air passengers from a given origin zone choosing a particular mode. In contrast, a *disaggregate* model attempts to predict how an *individual* decision maker with a given set of characteristics will behave. In the context of airport access mode choice, such a model typically attempts to predict the *probability* that a given airport user will choose a particular mode, because two airport users with apparently identical characteristics may well choose different access modes. If the probability of choosing each access mode is estimated for each airport user in a given sample of users, then the percentage of any group of such users choosing a given mode can be calculated. Because a disaggregate mode choice model predicts the probability of a decision maker choosing a given mode from

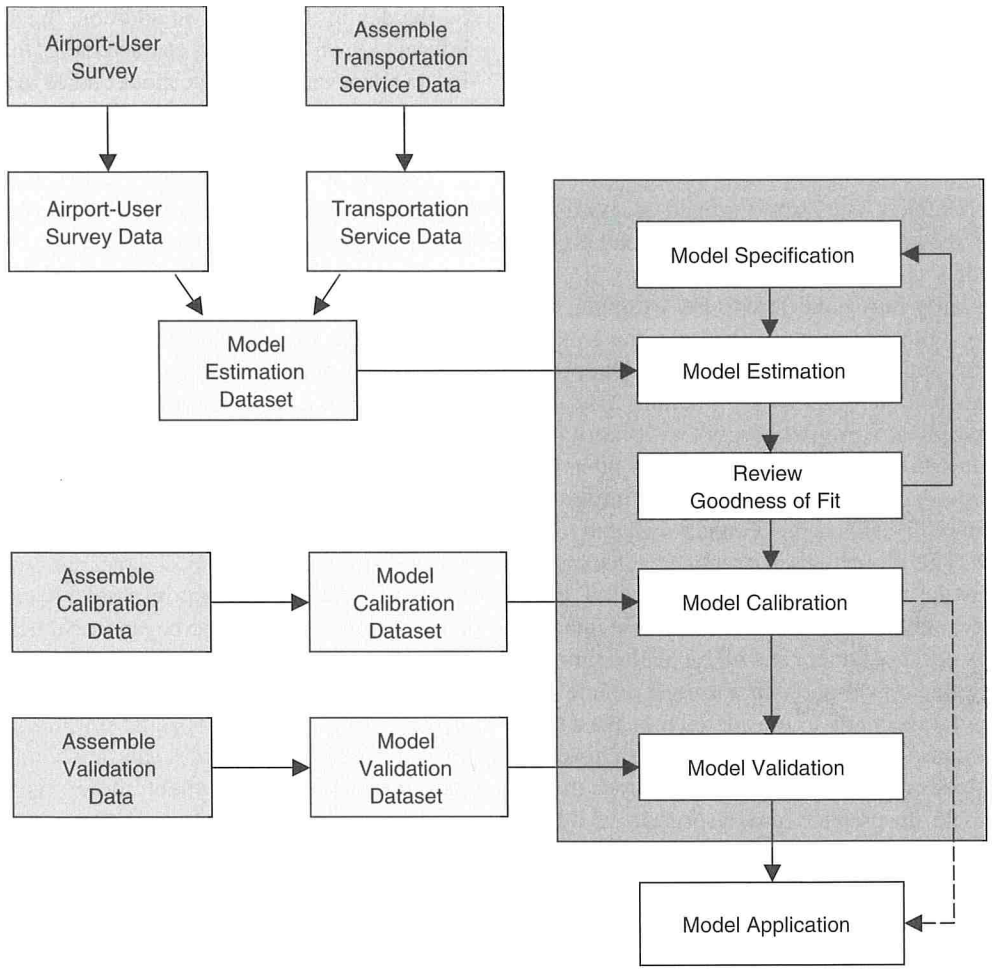

FIGURE 1 Mode choice model development process.

among a defined set of alternatives, these models are also referred to as *discrete choice* models.

Because the airport access mode choice decision depends on the characteristics of each individual travel party as well as the transportation characteristics of the different modes faced by that travel party, which in turn vary with the travel party characteristics (e.g., the travel costs typically vary with the access trip origin and the travel party size), most airport access mode choice models take a disaggregate approach. Indeed, it arguably impossible to develop a reasonable aggregate airport access mode choice model that adequately reflects all the relevant variables.

However, the decision to develop a disaggregate model imposes a number of constraints on the form of the model and the approach used to estimate the model coefficients. A mathematical form must be chosen for the model that predicts the probability of a given air travel party or airport employee choosing a given access mode. Suitable mathematical forms for the model are discussed in the next section. Because the model predicts the *probability* of a given decision maker choosing each of the available access modes but the estimation data give the access mode *actually chosen*, the statistical approach to estimating the model coefficients typically uses a *maximum* likelihood method rather than the more common statistical regression methods. The maximum likelihood method determines the value of the model coefficients that maximize the likelihood that the model will predict the mode actually chosen by each decision maker in the sample, where this likelihood is defined as the overall probability that the model predicts the actual mode choices (this is simply the product of the predicted probabilities of choosing the mode actually chosen across all the decision makers in the sample). Readers interested in more background on the mathematical details of estimating disaggregate choice models are referred to standard texts on the subject, such as Ben-Akiva and Lerman (1985) or Train (2003).

It should be noted that each data point (or record) in a dataset used to estimate a disaggregate choice model represents a single choice decision. In the case of airport access mode choice, air passengers often travel as a party of more than one person and the data point is the travel party, whether composed of one or more air passengers. Each travel party is considered to make the mode choice decision as a single unit,

whether or not the decision is made jointly by the members of the party or by one individual within the party. In contrast, airport employees are usually assumed to make airport access mode choice decisions individually, even if they decide to travel to the airport in a group (e.g., a car pool).

A further complication with airport ground access travel by air passengers that is commonly ignored in developing mode choice models is that the ground access travel party and the air travel party may be different. For example, two colleagues making a business trip together may travel separately to the airport and then meet up at the airport and fly together to their destination. Conversely, situations may arise in which the members of a ground access travel party take different flights after they reach the airport, such as attendees at a conference who decide to share a taxi to the airport. In these cases the unit of decision is the ground travel party, not the air travel party. Therefore, the access mode choice model should strictly predict the mode choice decision of each ground travel party, rather than each air travel party. Shared-ride modes such as a door-to-door van will typically combine more than one ground travel party in a single vehicle, although each ground travel party is considered to make a separate decision, because its members could have chosen a different access mode without affecting the decisions of the others on the vehicle. In practice, any error that would be introduced in an airport access mode choice model by ignoring the distinction between the ground access travel party and the air travel party is likely to be very small, because the distinction is only relevant for a small proportion of air travelers. However, it is a point that should be borne in mind when designing air passenger surveys that will collect data for use in developing airport access mode choice models, because it can affect the way that questions are worded.

Model Estimation Data

As noted earlier, model estimation data are obtained in two different ways:

1. Surveys of air passengers or airport employees, as the case may be; and
2. Assembly of transportation service data for each mode from operator and agency records and data files, published information, and other sources.

Survey Data

The air passenger or airport employee surveys obtain information on the access mode used for a specific trip, typically the most recent one. In the case of air passengers who are surveyed at the airport, this will usually be the access trip that they have just completed. In the case of airport employees, the survey may ask about access trips over a recent period, such as the previous week, to identify variation in access mode use from day to day or to reduce the effect of some special circumstance on the day of the survey. In addition, the survey will obtain information on respondent characteristics that may be used as independent variables in the mode choice model or to segment the data for model estimation.

The survey will also need to identify where the access trip began to determine the transportation service characteristics of the different modes that were faced by the respondent. The more accurately the trip origin location can be determined, the more precisely the corresponding transportation service levels for the various modes can be estimated. Because the data on transportation service levels are typically assembled on a zonal basis, the trip origin locations need to be expressed in terms of the system of analysis zones used for the transportation service data. The issues involved in selecting an appropriate system of analysis zones are discussed further later. However, with the possible exception of U.S. Postal Service zip code areas, most practical systems of analysis zones will not be such that respondents can be expected to know which zone their trip began in. Some respondents may even have difficulty with zip codes. Therefore, the usual approach is to attempt to obtain the street address of the trip origin or the name of a specific origin location, such as a hotel, for which the address can be obtained later. For privacy reasons, the exact street address is not required and typically the block number or a nearby street intersection is considered adequate. These addresses can then be geocoded and later assigned to the appropriate analysis zone.

The respondent characteristics that are used as independent variables or to segment the data will depend on the functional form of the model. Because this is typically not known at the time that the survey is conducted, but evolves during the model estimation process, the survey should attempt to collect information on those respondent characteristics that are believed to influence the mode choice process, even if some end up not being used in the model. Although there is a small cost to collecting data that are not used, if the information is not collected, one will never know how important it might have been in the model. The following is list of air passenger or airport employee characteristics that have either been shown to influence airport access mode choice or might reasonably be expected to do so.

- Air Passengers
  - Essential
    - △ Trip purpose (business vs. personal)
    - △ Resident of region or visitor
    - △ Primary ground access mode
    - △ How accessed primary mode (where relevant)
    - △ Where parked (if relevant)
    - △ Trip origin location (address, hotel name, etc.)
    - △ Trip origin type (residence, hotel, etc.)
    - △ Number of air passengers in travel party
    - △ Air trip duration (nights away on trip)
    - △ Household income
    - △ Household size.

  - Potentially useful (used in some models)
    - Amount of checked baggage
    - Number of air trips from airport in past year
    - Whether trip costs paid by employer or client
    - Time arrived at airport
    - Gender of respondent.
- Airport Employees
  - Essential
    - Primary ground access mode
    - How accessed primary mode (where relevant)
    - Where parked (if relevant)
    - Monthly parking cost (if any)
    - Whether any travel costs paid by employer
    - Trip origin location (home address)
    - Work location on airport
    - Times shift starts and ends
    - Variability of shift times
    - Household income
    - Household size.
  - Potentially useful
    - Job type/classification
    - Employer
    - Number of automobiles owned by household.

Some of the characteristics may appear directly in the mode choice model, whereas others are needed to determine the appropriate travel costs of the various modes. In the case of air passengers, the number of air passengers in the ground access travel party affects the relative cost of different modes, whereas the duration of the air trip affects the cost of parking for residents of the area. For those modes (such as rail transit or express airport bus) where a secondary access mode is needed to reach the primary mode, the access mode used will affect the cost and time of the trip. Some mode choice models may even model this access mode choice.

Accounting for income effects in mode choice models is problematic, as discussed elsewhere in this report, and many past models have ignored the issue entirely. However, clearly income must have some effect on airport access mode choice. Household income may be a more appropriate measure than individual income, because this reflects the contribution of other members of the household in covering basic household costs; however, at the same time the discretionary income for a given level of household income will also depend on the size of the household.

As important as deciding what information should be collected in the survey is deciding how to word the questions. Poorly worded questions will produce unreliable data, because respondents may misunderstand the question and give an incorrect answer. In the case of self-completed surveys, this applies not only to the questions themselves, but also to any predefined response options that are provided. The design of survey questionnaires and question wording is a topic in its own right and beyond the scope of this report. However, an ACRP study currently underway (Project ACRP 03-04) is developing a "Guidebook for Airport-User Surveys," which will provide detailed guidance on these and other related issues.

Stratified Sampling

Because the use of different transportation modes for airport access varies widely, and in particular at many airports public transportation has a fairly small market share, surveying a random sample of air travelers (e.g., in airport terminal departure lounges) will result in relatively few respondents who used the less common modes. This will in turn adversely affect the ability of a model estimated on that data to explain the choice behavior of the respondents using those modes. One approach to overcoming this problem is to perform *stratified sampling*, in which the survey is done in a way that obtains a greater number of responses from a particular subset of travelers than would be expected from a truly random sample. For example, surveys could be performed where passengers alight from transit vehicles. Alternatively, the survey could be done in a location where respondents selected at random will intercept all types of travelers, but a screening question asked at the start of the survey will identify respondents in the subset of interest and the survey of those respondents will be performed in more depth.

Estimating mode choice models on the basis of data obtained from a stratified sample requires some adjustments to the standard model estimation techniques to weight the response data in the estimation process; however, these adjustments are discussed in most standard textbooks on discrete choice modeling. Similarly, in presenting the results of a stratified sample, it is important to weight the responses appropriately to reflect the correct distribution of respondent characteristics across the population of airport users as a whole. Developing appropriate response weights for both model estimation and presenting survey results requires data on the frequency of occurrence of the different categories of respondent. These weights can be obtained from actual traffic counts of the different respondent categories where these are available or by comparing the results of the stratified sample with that of a random sample of the larger population of air passengers or airport employees as the case may be.

Transportation Service Data

To calculate the travel times and costs faced by each travel party in using the different airport ground transportation services, it is necessary to assemble the transportation service data for each mode on the basis of a defined system of analysis zones so that the appropriate value of any particular service characteristic for a given travel party can be determined from the trip origin zone for that party. Some data, such as the highway travel time to the airport, will vary across the zones. Other data, such as daily airport parking rates, are independent of the trip

origin zone and thus constant for every zone, although the cost for parking will depend on how long the vehicle is parked. Some costs, such as fares for some public transportation services will depend on both the origin zone and the number of people in the travel party.

Highway travel times, highway distances, and transit travel times and fares are typically available from the regional transportation planning agency. However, modes such as taxi, shared-ride van, and scheduled airport bus, which are not usually included in the regional travel demand model, will require some work to assemble the necessary data. The ground transportation information pages of the airport website may have current information on many of the ground transportation services and parking rates. Otherwise, it may be necessary to contact the individual operators to obtain fare and schedule information. In the case of scheduled services with defined stops or stations, the schedule will generally provide headways and travel times from each stop or station. It will be necessary to determine the analysis zone for each stop, as well as the analysis zones served by that stop and the transportation service characteristics (travel times and costs) for the secondary access trip to reach the stop from each zone served by the stop. Because there may be several alternative secondary access modes (such as walk, drop off by private vehicle, taxi, or public transit), the transportation services characteristics will have to be determined for each mode and each analysis zone.

The result of this process is a large data table with a row (or record) for each analysis zone and the transportation service variables for each mode and sub-mode forming the columns (or position in the record). The appropriate transportation service values can then be assigned to each travel party in the model estimation dataset by looking up the relevant data for the trip origin analysis zone for that party and computing the values where necessary to account for the travel party size, air trip duration, or other travel party characteristics that affect the value of the transportation service variable for that party.

Analysis Zones

Selection of a suitable system of analysis zones involves a tradeoff between the precision of the transportation service data used for each travel party in the sample and the work involved in assembling the necessary data. Some of the data may already be available in a particular system of analysis zones. For example, regional transportation planning agencies will generally have computer files with highway travel times between each transportation analysis zone (TAZ) used in their regional travel demand model and the TAZ containing the airport. Indeed it may be desirable or even required that an airport access mode choice model is based on the regional travel demand model TAZ system so that the results of the modeling can be integrated with the regional travel demand modeling process.

However, a large metropolitan region may easily have more than 1,000 TAZs, and some larger regions have significantly more than that. The current regional travel demand model for the San Francisco Bay Area utilizes 1,454 TAZs, whereas that for the Washington metropolitan area utilizes 2,191. For those travel variables that can be obtained directly from the regional transportation modeling datasets, such as highway times or transit fares, this is not a particular problem. However, for other modes, such as shared-ride van, where fares are not typically available from the regional datasets, or are usually expressed in terms of the TAZs, obtaining the relevant data and converting it to the TAZs can be a major task.

It might appear that the data management problem can be reduced somewhat by using larger zones, such as U.S. Postal Service zip code areas. However, apart from the loss of precision involved in using larger zones, most transportation service data are not available on a zip code basis anyway, so the work involved in converting the data to a zip code-based system may not be significantly less than using TAZs. Where data are available by zip code (e.g., some shared-ride van operators base their fares on zip codes), it is fairly easy to develop a mapping from zip code areas to the corresponding TAZs and convert the data to a TAZ basis. Most geographical information systems have functions that can do this automatically provided that the TAZ boundaries are available as a geographical information systems file.

Revealed Versus Stated Preference

There are two different approaches to assembling the necessary data on airport access mode choice behavior to develop mode choice models: revealed preference and stated preference surveys. Revealed preference surveys identify the travel choices actually made by airport travelers, as well as collect information on other traveler characteristics and details of the trip that are believed to influence the choice. The model estimation process attempts to develop a model that explains the mode choice decisions in terms of the traveler characteristics and the service characteristics of the different airport ground access modes available to the traveler.

Stated preference surveys follow a similar process, except that the respondent is presented with a set of hypothetical choices and asked to select from them. For realism, the stated preference experiment is usually structured so that the choices presented to the respondent correspond to their current trip or a recent actual trip but change the characteristics of the ground transportation options available, such as different prices or travel times or the introduction of a new service or mode. Estimating a mode choice model on such data allows the model to incorporate ground access options that do not currently exist or to explore the effect of changing factors that do not exhibit much variation in the real world. Although this is a powerful capability, there are concerns about how well

travelers' expressed choices between hypothetical situations that they have not actually encountered correspond to how they would really behave if faced with those situations in practice. To attempt to address this concern, stated preference studies are often combined with analysis of revealed preference to at least ensure that the stated choice behavior is consistent with the actual behavior when applied to situations that have actually been experienced.

Even so, there remains the concern that survey respondents may overstate their willingness to use new alternatives that do not yet exist, whether out of a desire to appear responsive to the survey or because they misinterpret how attractive the new service will be relative to their current choices. There is a limit to how detailed the description of a new service can be in the context of a stated preference survey that has to be completed in a fairly short time period, and respondents may not fully consider all the factors that would arise in using the new service, such as how they would get to it at the time that they need to travel. A related factor is that a stated preference survey necessarily informs the respondents about the options that are hypothetically available so that they can make a choice. However, in practice many travelers may not be aware of the existence of the service or may have a misperception of the nature of the service offered.

Habit and Information

An important aspect of air passenger airport access mode choice is the role of travel habits and the awareness of travel alternatives. In contrast to most urban trips, such as the journey-to-work or shopping trips, most air passengers do not make air trips that often, and many visitors to a region may be visiting for the first time. It is self-evident that travelers will not choose to use modes that they do not know exist, or even if they have significant misperceptions about the nature of the service offered, such as the travel time involved or the cost. However, most air passenger surveys ignore questions of travelers' awareness of difference services and their perceptions of the service offered by modes that they did not use. As a result, the estimation process of most mode choice models has implicitly assumed that travelers have full information about each mode. The issue of how to address habit and information in airport access mode choice models (or any models of travel behavior for that matter) is not well understood and is one that could benefit from further research.

This is an important consideration because it directly addresses the role of marketing in the provision of airport access services. Airport authorities or transportation operators can choose to spend resources improving services or more intensively marketing the services that they already provide. It would be extremely helpful if airport access mode choice models could help shed some light on how best to allocate resources between service improvements and marketing. However, for this to happen it will be necessary to incorporate traveler information more explicitly in the models.

Model Specification, Estimation, Calibration, and Validation

The terms model estimation and model calibration are often loosely used interchangeably. However, strictly speaking they are two different steps in developing an airport access mode choice model (or indeed any model). *Model estimation* refers to the use of statistical procedures to determine the values of the model coefficients that best fit the data from which the model is being developed. Typically, this will be derived from a sample of air passenger or airport employee trips obtained from a survey.

Once an estimation dataset has been assembled, the first step in model estimation is *model specification*. This involves selecting an appropriate functional form and market segmentation for the model, and defining relevant explanatory variables. Model estimation software is then used to obtain estimated values of the model coefficients. The statistical significance of these estimated values and the overall goodness-of-fit of the model is examined and the model specification revised as necessary to address problems with the resulting model coefficients or statistical fit. Model development typically proceeds iteratively. A fairly simple functional form with relatively few explanatory variables is initially estimated. Then the model is improved progressively by adding variables or modifying the functional form, such as changing the structure of the way that modes are grouped within the model to improve the statistical fit of the model to the estimation data. However, statistical fit is not everything. A model must also make sound behavioral sense. A model that reflects a plausible structure of behavioral causality is generally preferred to one that contains counterintuitive features, even if the latter has a better statistical fit.

Once a satisfactory model has been estimated, model calibration should be undertaken to make any necessary adjustments to the model so that the model predictions agree with observations. If the model estimation has been done correctly, the model predictions will agree with the observed data in the model estimation dataset. However, because these data may not be a truly representative sample of the larger population being modeled, the model may need to be adjusted to produce satisfactory predictions. In the case of an airport access mode choice model, where the composition of the air travel market will vary seasonally or even from day to day and assumptions will need to be made about average vehicle occupancy of some modes to convert the number of person-trips using those modes to the equivalent number of vehicle trips, the total volume of vehicle trips by each mode predicted by the model using the estimated coefficients may differ from the observed volume of vehicle trips for any given period. This is particularly the case when a model has been estimated on survey data collected at one point in time,

typically a few weeks or less, but is being used to predict mode use for a different time period, such as a year.

Even if the survey data used for model estimation is an accurate representation of the larger population, the conversion of model predictions from travel party trips to vehicle trips generally will require some model calibration. Because access mode choice models are estimated on data for a sample of air passenger travel parties or airport employees, they generate predictions of travel party or employee trips using each mode, which typically need to be converted to vehicle trips for use in planning studies or other applications. For most private vehicle modes the conversion is straightforward, because each travel party generates one vehicle trip in each direction (or two in the case of drop off or pick up by private vehicle). However, for most other modes the ratio of vehicle trips to travel party or employee trips depends on assumptions about average vehicle occupancy or (in the case of modes such as taxi or limousine) the proportion of deadhead trips to revenue trips. For scheduled modes, the number of vehicle trips is determined by the schedule rather than the mode use. Where observed counts of vehicle trips are available, it will generally be necessary to adjust the assumptions about average vehicle occupancy or proportion of deadhead trips to match the predicted values of vehicle trips to the observed values.

Model validation is the final step in model development and involves comparing the predictions of the model under different conditions from those under which it was estimated and calibrated, usually after some change has occurred in the system being modeled, with the actual values of the phenomena being modeled. In the case of an airport access mode choice model, this could involve comparing projections of mode use in subsequent years or after changes have occurred in the ground transportation services available at the airport with the observed mode use under those different conditions. Although limited model validation can be done using partial data on the use of certain modes, such as comparing the number of private vehicles parked at the airport with the number projected by the model, a more thorough model validation will require an extensive effort to collect comprehensive data on mode use for the validation period.

Because the pattern of access mode use at an airport will depend on the composition of the air travel market or of the employee workforce, as well as the transportation services available, a true validation of an access mode choice model should include a new air passenger or airport employee survey to ensure that the market composition assumptions being used in the modeling are correct. Otherwise, it is unclear whether differences between the predicted mode use and the observed mode use are the result of problems with the model or invalid assumptions about the market composition. Similarly, it is important that the transportation service assumptions for the various modes that are used in the modeling are updated to reflect changes in costs and service levels since the model was originally developed.

Because of the effort and resources required to assemble the necessary data to perform a proper validation of an airport ground access mode choice model, such validations are rarely if ever done and it is simply assumed that a calibrated model that has been developed from data on mode use patterns at one point in time will remain valid when used to model airport access mode use at other points in time or under different conditions. Also, because model validation involves comparing model predictions with observed conditions under different conditions from those from which it has been calibrated, this often cannot be done until some time after the initial model estimation effort, by which time it may already have been used for the application for which it was developed. However, airport access mode choice model development should not be viewed as a one-time effort, any more than any other aspect of travel demand analysis. Rather, opportunities to validate a model should be sought and pursued following its initial development, and the model refined and improved over time. In this way the model will be available for subsequent applications with a growing level of confidence in its predictive reliability.

MATHEMATICAL FORM OF TYPICAL MODE CHOICE MODELS

The challenge of developing mathematical models of discrete choice behavior has attracted the interest of statisticians, economists, social scientists, and transportation planners over a long period of time and thus not surprisingly there is an extensive literature on the subject that is beyond the scope of this report to summarize. Some of the earliest applications of discrete choice behavior models to transportation travel demand were undertaken by Daniel McFadden and colleagues (described in Domencich and McFadden 1996), as part of work for which McFadden was awarded the Nobel Prize in economics. Readers interested in the theoretical background and evolution of the current state of practice of transportation mode choice models can refer to standard texts such as Ben-Akiva and Lerman (1985) or Hensher et al. (2005). However, to help readers who have limited or no prior familiarity with these techniques understand the general approach; this section will attempt to provide a simplified introduction to the current state of practice. Those with some familiarity with transportation mode choice modeling may choose to skip this discussion.

The basic concept underlying most disaggregate discrete choice analysis is that each alternative in the choice set provides the decision maker with some *utility* that can be expressed in terms of measurable or observable characteristics of both the decision maker and the alternative (e.g., the travel time involved or the income level of the decision maker). The larger the difference in the utility between two alternatives, the more likely the decision maker is to choose the alternative with the higher utility. This can be illustrated by the relationship shown in Figure 2, which shows the probability of choosing alternative 1, $P(1)$, as a function of the

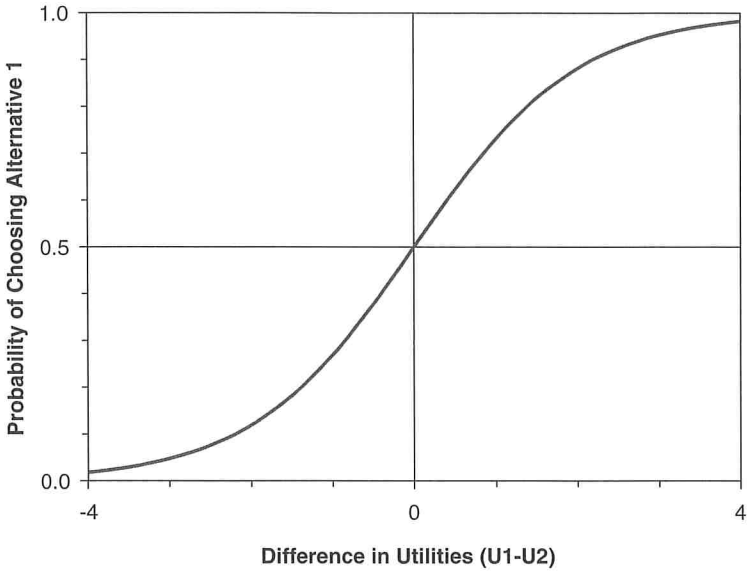

FIGURE 2 Illustrative binary choice relationship.

difference between the utility of alternative 1, $U1$, and that of some other alternative 2, $U2$, (termed a binary choice because it involves only two alternatives). As this difference becomes large and positive (i.e., the utility of alternative 1 is much greater than that of alternative 2), the probability of choosing alternative 1 approaches one (a probability by definition must lie between zero and one). Conversely, if the difference in utility is large and negative (i.e., the utility of alternative 2 is much greater than that of alternative 1), the probability of choosing alternative 1 approaches zero. If the difference in the utilities is zero, the two alternative are equally attractive and the probability of choosing either is equal to 0.5 (50%).

Multinomial Logit Model

As shown in Figure 2, the functional relationship between the difference in utility and the probability of choosing a particular alternative will be an S-curve, because it must be asymptotic to one and zero as the utility difference becomes very large in either the positive or negative direction. Early work on choice modeling identified the *logistic function*, defined as:

$$f(x) = e^x/(1+e^x) = 1/(1+e^{-x})$$

as providing a suitable S-shaped curve, where e^x is the exponential function of x. It can be seen that as x becomes very large and positive, $f(x)$ approaches one and as x becomes very large and negative, $f(x)$ approaches zero.

In the context of a choice model between two alternatives (termed a binary or binomial choice) the logistic function can be restated as:

$$P(i) = 1/\left(1+e^{-(U_i-U_j)}\right)$$

where U_i and U_j are the utilities of alternatives i and j, respectively, and $P(i)$ is the probability of choosing alternative i. This in turn can be reexpressed as:

$$P(i) = e^{U_i}/\left(e^{U_i}+e^{U_j}\right)$$

which became known as the *logit* model (strictly the *binomial logit* model). It can be shown fairly easily that with more than two alternatives the model can be extended as follows:

$$P(i) = \frac{e^{U_i}}{\sum_{j\in J} e^{U_j}}$$

where J is the number of alternatives. This is termed the *multinomial logit* (MNL) model and has been widely used for airport access mode choice models, because most airport access mode choice situations involve more than two alternatives.

Although the logit model was initially simply a convenient way of generating the required S-shaped relationship, later work showed that under certain assumptions regarding the form of the utility terms the logit model can be derived from theoretical principles of utility maximization, whereby the decision maker chooses the alternative that offers the highest utility, and the probability of choosing a given alternative is thus given by the probability that that alternative offers the highest utility of all the alternatives.

Utility Function

In developing discrete choice models, the utility of a given alternative is assumed to comprise two parts; a *deterministic* part that consists of a function of measured and observed

variables and an *error* term that accounts for unobserved characteristics and variability in the perceived utility of a given set of characteristics across different individuals, therefore:

$$U_i = V_i + \varepsilon$$

where V_i is the deterministic part of the utility and ε is the error term. In logit choice models, the error term is assumed to be a random variable with values that are independent and identically distributed with a Gumbel (double exponential) distribution with a zero mean. (This assumption allows the logit model to be derived from utility maximization theory.) The variance of the error term reflects the goodness-of-fit of the model.

The deterministic part of the utility function typically consists of a linear combination of explanatory variables with their associated model coefficients, the values of which are determined in the model estimation process, therefore:

$$V_i = a_i + b_1x_1 + b_2x_2 + \cdots + b_nx_n$$

where a_i and the b's are the model coefficients and the x's are the values of the explanatory variables, such as travel time and cost. In general, the utility function for each alternative will have a constant term a_i, known as the alternative-specific constant (ASC), which reflects attributes of the alternative that are not accounted for by the other variables. Therefore, a fairly simple utility function might comprise:

$$V_i = a_i + b_1(\text{travel time}) + b_2(\text{waiting time}) + b_3(\text{walk distance}) + b_4(\text{cost/income})$$

Note that in this example travel cost is divided by household income in the fourth explanatory variable so that the choice process becomes less sensitive to cost for higher income travelers. This is included as an illustration that all explanatory variables do not have to enter the utility function as separate terms and may not be the best way to reflect the effect of household income.

It should also be noted that changing the utility functions of each alternative in a logit choice model by the same amount will not affect the resulting probabilities (because the change will factor the numerator and denominator of the logit expression for each alternative up or down by a constant amount that will cancel out). Therefore, it is usual practice to set the ASC for one of the alternatives to zero, so that the ASCs for the other alternatives then reflect the differences in the constant part of the utility for those alternatives relative to the alternative without an ASC.

The estimated coefficients of the utility function can be thought of as weighting factors that convert the units of the explanatory variable (e.g., minutes of travel time) to a measure of perceived utility. Because perceived utility is an abstract concept that has no intrinsic units of measurement, the estimated values of the coefficients have no direct interpretation. However, the ratio of the coefficients for two variables (or the ratio of the ASC to a coefficient of an explanatory variable) is another matter. This ratio expresses how an increase in one variable (or the ASC) will offset a decrease in the other variable and thus can be expressed as implied values. The ratio of a given coefficient or ASC to the coefficient for the cost term gives the implied value of that variable or constant in the units of the cost term. With appropriate adjustments for the units of two variables, this can give implied values of time in dollars per hour. Where the travel cost variable incorporates some function of household or other income the resulting implied values will be expressed in terms of this income measure.

This has an important implication for the specification of the utility function. Although different components of travel time can (and often should) be expressed with separate variables, cost terms should be combined into a single variable. This will avoid problems with the model giving different implied values of a given variable depending on which cost term coefficient is used. This is also conceptually sound. Although travelers may (and usually do) perceive different components of travel time as having a different disutility per unit time (i.e., different implied values), it would be surprising if they view a dollar spent on one aspect of the airport access journey any differently from a dollar spent on another aspect, because the money involved is completely interchangeable. (The one exception to this principle would be if some travel costs are reimbursable and others not. In this case, it would make sense to use separate variables for the two types of cost so that the ratio of the two cost coefficients reflect the relative importance of reimbursable to nonreimbursable costs. This would still allow values of time to be expressed consistently in terms of nonreimbursable costs.)

Limitations of Multinominal Logit Model

Although the MNL model has been widely used, it is vulnerable to problems that arise from a property of the model termed the "Independence from Irrelevant Alternatives." This states that including a new alternative in the choice set (or changing the perceived value of one of the alternatives) should not affect the relative probabilities of choosing any of the other alternatives. It can be seen from the previous equation for the MNL model that the ratio of the probability of choosing any two alternatives is determined only by the perceived utilities of those alternatives.

However, in many situations in airport access mode choice it is quite unlikely that changing the characteristics of one mode or sub-mode will leave the relative probabilities of choosing all the other modes and sub-modes unchanged. For example, increasing the parking rates in the short-term parking lot is likely to have a greater effect on

the probability of an air party choosing to park in the long-term parking lot than on the probability of choosing to use a shared-ride van, because those who would have parked in the short-term lot at the former rates are much more likely to choose to park in the long-term lot instead than to decide to use a shared-ride van. Similarly, changes in one public transportation service are likely to affect the use of other public transportation services to a greater extent than the use of private vehicles.

This is not usually a significant problem with a model that only includes a limited number of well-differentiated modes, but becomes increasing problematical with models that attempt to distinguish between the use of similar modes (such as taxi and limousine) or to account for sub-modes (such as different parking facilities).

Nested Logit Model

The limitations of the MNL model can be addressed by grouping similar modes or sub-modes into separate groups or *nests* in a choice structure referred to as a *nested logit* (NL) model, as illustrated by Figure 3. In the nested model shown in the figure, alternative *b* consists of a second-level nest of two sub-alternatives, *b*1 and *b*2, the second of which consists of a third-level nest of two further sub-alternatives, *b*21 and *b*22. For example, alternative *b* might represent the use of a private vehicle, with alternative *b*1 representing the air party being dropped off at the airport and *b*2 the use a private vehicle that is parked at the airport for the duration of the air trip, where *b*21 represents the use of the short-term parking lot and *b*22 the use of the long-term parking lot.

The general form of the NL model is similar to the MNL model, with the addition of a scaling parameter μ_m for each nest m, as follows:

$$P(i|m) = \frac{\left(e^{U(i)}\right)^{\frac{1}{\mu_m}}}{\sum_{j \in N_m} \left(e^{U(j)}\right)^{\frac{1}{\mu_m}}}$$

$$P(m) = \frac{\left(\sum_{j \in N_m} \left(e^{U(j)}\right)^{\frac{1}{\mu_m}}\right)^{\mu_m}}{\sum_{l \in S} \left(\sum_{k \in N_l} \left(e^{U(k)}\right)^{\frac{1}{\mu_l}}\right)^{\mu_l}}$$

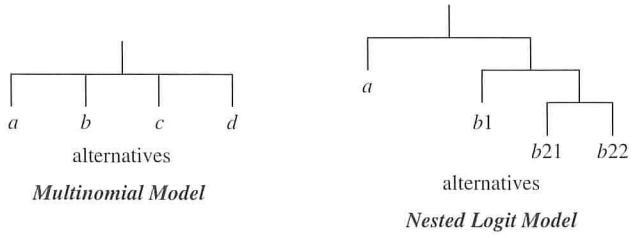

FIGURE 3 Multinomial and nested logit models.

where $P(i|m)$ is the probability of choosing mode i in nest m from among the set N_m of modes in nest m, given that nest m is chosen (strictly that a mode in nest m is chosen) and $P(m)$ is the probability of choosing nest m from the set S of nests at the same level as nest m. If one branch of a nest consists of a discrete mode m^* rather than a lower-level nest, the value for the scaling parameter for that mode $\mu_{m^*} = 1$. Therefore, if there is only one nest, the previous equations reduce to the MNL model.

Estimation of NL models involves estimating values for the scaling parameters as well as the utility function coefficients.

Other Model Specifications

Although the NL model overcomes some of the inherent limitations of the MNL model, there remain a number of other limitations to the use of NL models for modeling airport access mode choice. Perhaps the most significant of these is the assumption that the variance of the error term in the utility function is the same for all air parties and all alternatives. Another limitation can arise where the same alternative appears in different nests; for example, if several public transportation alternatives have station or stop access sub-mode nests, because these will typically involve the same sub-modes. Efforts to explore alternative model formulations to NL models for transportation mode choice applications have taken two approaches. One is to use more advanced logit model formulations that address some of the limitations in the standard model. The other is to use an entirely different conceptual approach to representing the mode choice process.

However, to date neither of these approaches has been applied to stand-alone airport ground access mode choice models, although some work has been done on modeling airport choice in which ground access mode choice forms part of the choice process (Hess and Polak 2005, 2006). Although these alternative approaches may be a promising area for future research, given the limited experience applying approaches other than MNL and NL models to airport ground access, the details of these approaches are not discussed further here. Readers interested in more information will find a discussion of the potential application of alternative mode choice model approaches to airport access travel in Lu et al. (2006).

MODEL ESTIMATION CONSIDERATIONS

Apart from questions of selecting an appropriate functional form and market segmentation for the model and defining relevant explanatory variables, careful consideration needs to be given to developing the necessary estimation dataset. The reliability of the resulting model is critically dependent on the accuracy of the data on which it is estimated. If the data contains errors or biased values of explanatory variables, the model will attempt to explain the traveler behavior

in terms of those values rather than the real values. This may not be a problem in obtaining a good fit to the data, but will produce biased predictions when the model is later applied to other datasets that do not have the errors or biases.

Model Estimation Software

The process of estimating airport access mode choice models, such as mode choice models for other transportation applications, requires specialized software that is designed to perform maximum likelihood estimation with fairly complex model specifications. This software falls into three broad categories:

1. Special-purpose commercial software that has been developed specifically to estimate logit-type choice models or the mode choice component of transportation planning models.
2. General purpose commercial statistical packages that include modules for performing maximum likelihood estimation of discrete choice models.
3. Software developed by academic researchers to estimate a fairly broad class of econometric models that includes discrete choice models.

As might be expected, there is typically a tradeoff between the ease of use and cost of the different categories of software. Special-purpose commercial software for estimating logit choice models or transportation mode choice models is often the easiest to use, because considerable attention has been given to the design of the user interface and the software has been specifically developed for this purpose. However, the software is often more expensive than the other options, although the cost of acquiring software is usually small compared with the overall cost of the model development process.

A number of general purpose statistical software packages provide the capability to estimate discrete choice models using maximum likelihood techniques. Sometimes this requires the purchase of an additional software module. Although the cost of this additional capability (if required) is usually less than acquiring special-purpose software, estimating a model with this software may require somewhat more effort than using special-purpose software, although the interface between the model estimation function and the data management capabilities of the package is usually straightforward. This may be an attractive option for organizations that already are using one of these software packages for general statistical analysis.

Software developed by academic researchers to estimate various types of econometric models, often in support of their research or teaching activities, is often available at little or no cost. Depending on the scope of the software, this may require some customization to use to estimate a particular model specification. Documentation, user interface, and data management features are often fairly basic, and user support may be limited or nonexistent. On the other hand, the software may contain features or provide capabilities that are not available in commercial packages. A good example of this class of software is BIOGEME, developed by Michel Bierlaire at the Ecole Polytechnique Fédéral de Lausanne, Switzerland (Bierlaire 2003), and available on the Internet at http://biogeme.epfl.ch.

Unfortunately, obtaining comparative information on different software options is not as easy as might be thought. With some persistence, Internet searches can generally locate information on the principal software packages. However, some creativity is required in defining the search expressions to avoid being swamped by links to articles about choice model estimation methodology rather than the software involved or econometric software in general.

Market Segmentation

The air passenger market is not homogeneous and different market segments have different airport access needs and available options. The most obvious distinction is between residents of the local area and visitors. Residents typically have access to a private vehicle and often someone who can take them to the airport or pick them up. Visitors on the other hand may need to rent a car to meet their transportation needs while in the area or may be staying at a hotel that does not provide a courtesy shuttle service to the airport. Another important distinction is between those traveling on business trips, whose travel costs may be reimbursed by their employer or client, and those making trips for non-business purposes. These distinctions are typically addressed by defining different air passenger market segments and estimating a separate sub-model for each segment. The market segment sub-models may include different modes, may use different explanatory variables, and will generally have different estimated coefficients for a given variable.

Although a common market segmentation approach, discussed in more detail in subsequent chapters, is a four-way division into resident business trips, resident non-business trips, visitor business trips, and visitor non-business trips, other market segments may be worth considering. One is to differentiate visitors staying in a hotel from those staying with relatives or friends, because the latter may have access to private vehicles owned by the people they are staying with as well as people who can pick them up or drop them off at the airport.

Changes in the Airline Industry

The terrorist attacks of September 11, 2001 (9/11) have led to dramatic changes in the airline industry, in particular passenger security processing at airports. No longer can greeters and well-wishers enter the secure side of airport terminals,

and passengers need to arrive at the airport earlier than before to ensure being able to clear security in time to make their flight. In addition, airports rigorously enforce the prohibition on leaving vehicles unattended at the terminal curb front or even waiting when not actively loading or unloading passengers. The combined effect of these measures has been a significant change in airport ground access mode use. Fewer well-wishers accompanying passengers to the airport (or drivers dropping passengers off at the airport) park for a short time to accompany the passengers into the terminal, because the passengers are usually anxious to get through security as quickly as possible and the well-wishers cannot accompany them. Similarly, greeters can no longer meet arriving passengers at the gate, and the increased use in cell phones over the past five years has simplified the process of picking up arriving passengers at the terminal curb front. As a result, many airports have introduced cell phone lots where drivers picking up air passengers can wait until the passengers are ready to be picked up.

Another significant change in the airline industry since 9/11 is a reduction in the percentage of short-haul trips. This is widely believed to be at least in part a result of the need to arrive at the airport for a flight earlier than before, which increases the time required to make an air trip and in turn makes driving or other surface transportation modes relatively more attractive. There may also be a heightened concern over aviation security that leads some who do have a surface transportation alternative to take this option even if it involves more time than flying. A third consideration is the increasing market share of low-fare airlines and the competitive response of the network carriers. This has led to a much higher proportion of air travelers using low-fare or heavily discounted tickets. It would seem likely that passengers attracted to air travel by cheaper fares would also be more cost-sensitive when making their airport access decisions. It is also likely that a higher proportion of air travelers are flying for personal rather than business reasons, although that has also been affected by cyclical changes in the economy.

Although these changes in the airline industry do not fundamentally affect the basic approach to modeling airport access mode use, they do affect the relative attractiveness of the different transportation services represented in the model and hence the estimated model coefficients, as well as the market composition. Any airport access mode choice model estimated on data from before 9/11 is likely to produce biased predictions of current or future air passenger access behavior. Similarly, current data on air passenger market composition, particularly the split between business and non-business travelers and the distribution of trip durations, is likely to have changed significantly from data collected before 9/11.

Level of Effort Required

It is clear from the foregoing discussion that developing an airport ground access mode choice model is not a simple or inexpensive matter. This raises the questions of how large an airport needs to be to justify the effort and what such an effort might cost, not easy questions to answer. For most large airports, with complex ground access systems to plan and manage, it is very difficult to conceive how this can be done well without such a model (although many airports try to make do without one). For smaller airports, perhaps with traffic levels in the range of 5 to 10 million annual passengers, the need may depend on the type of planning issue being faced.

The resources needed to develop an airport access mode choice model depend in part on the availability of air passenger survey data (or airport employee survey data in the case of employee access mode choice models). As discussed earlier, good air passenger survey data are critical to model development. Experience suggests that for adequate model development such a survey should have at least 3,000 responses, although models have been developed with smaller sample sizes. Stated preference surveys have been conducted with fewer respondents, approximately 800 and 1,100 in two recent cases; however, each respondent typically answers several choice experiments, each of which provides a data point, and such surveys cost more to perform per respondent than a revealed preference survey. Although the cost per completed survey of a revealed preference survey can vary significantly with local circumstances as well as the number of questions asked, typical costs identified in an on-going ACRP study of airport-user survey methodology (Project ACRP 03-04: "Guidebook for Airport-User Survey Methodology") are in the range of approximately $30 to $50 per completed response.

This suggests that developing the necessary survey data might cost somewhere in the range of $90,000 to $150,000. Assembling the corresponding transportation service data is also not trivial, although the local MPO may be able to provide some of these data in electronic format from the regional travel demand model network data. The amount of work involved in assembling the remaining data required will depend in part on how much information the airport authority already has available on the ground transportation pages of its website or in other files. Overall, this task might require between one and two person-months of effort and cost somewhere between $20,000 and $50,000 at typical consultant rates. Once the necessary data have been assembled, estimating, calibrating, and validating the model might require two to three person-months of effort, or perhaps between $40,000 and $75,000. Therefore, a complete study, including an air passenger survey, might cost between $150,000 and $275,000. However, the largest part of this cost is performing the air passenger survey, which has other value for airport planning purposes and should be done periodically anyway.

Whether such an investment is worthwhile depends on what the resulting model would be used for and the likely cost of making a bad decision. Certainly, in the case of evaluating

the feasibility of a major infrastructure investment such as an airport rail link or even an automated people-mover link to a nearby rail station that might cost several hundred million dollars or more, the cost of having a good modeling capability is trivial and would easily be justified by avoiding a poor decision that results in an increase in the cost of the project by even 1%. Indeed, having such a modeling capability is probably a necessary requirement for obtaining environmental approval and funding. In the case of a smaller airport where the issues being addressed involve less money, the justification for such a modeling capability is less clear. Even so, an airport handing 5 million annual passengers, 20% of whom park at the airport for their trip duration, could be generating as much as $10 million per year in parking revenue. An increase in revenue of only 3% as a result of better pricing decisions could pay for the cost of developing the modeling capability in less than year.

MODEL APPLICATION

Once a mode choice model has been developed, to apply it to support planning and decision making it is necessary to have the ability to use it to analyze specific scenarios. This typically involves a significant amount of data management and model configuration to define the scenarios to be analyzed. One approach is to use the model in conjunction with standard transportation planning software or proprietary airport landside modeling software. These software tools are designed to facilitate the data management involved in modeling transportation network flows and typically provide users with the flexibility to define the structure and coefficients of the mode choice model incorporated in the analysis. If such models are not available, or the models that are available do not have the necessary capabilities, it will then be necessary to develop custom software to apply the model to analyze any given scenario.

Many discrete choice model estimation tools also provide the capability to apply a defined choice model to any suitably configured dataset of decision-maker characteristics and associated properties of the choice alternatives to estimate the resulting choice probabilities. The result of this process is typically a table of the probability of choosing each alternative for each decision maker (air passenger travel party or airport employee) in the dataset. Converting this table to a projection of passenger trips or vehicle trips by mode is then a matter of factoring up the results to correspond to the total airport activity for the period in question and applying the appropriate ratios of vehicle trips to travel party or employee trips. These estimated vehicle trips can in turn be allocated to the transportation network by segmenting the results by the trip origin zone and creating a zonal trip table. Although conceptually this is not difficult and the required calculations can generally be performed fairly easily using spreadsheet or database management software, because the process typically has to be repeated multiple times to analyze a number of scenarios it may be helpful to develop utility routines to perform the various steps.

Model Application Considerations

Although the process of applying an airport access mode choice model is technically fairly straightforward, there are a number of aspects that need to be carefully considered in developing the required input data and interpreting the results.

The first is that whereas a relatively small survey sample size (a few thousand respondents in the case of air passengers and perhaps even fewer for airport employees) may be adequate to estimate an airport access mode choice model, a much larger sample may be required for a given application of the model, depending on the issues of interest and the desired level of geographic resolution of the results. For example, a study to estimate the likely use of a proposed off-airport terminal in a particular location in the region served by the airport needs to have enough data points in the application dataset in the vicinity of the proposed terminal that the resulting estimate of the likely use of the facility is sufficiently accurate. To create a large enough application dataset, it may be necessary to develop a synthetic sample using Monte Carlo simulation methods based on the distribution of travel party characteristics in the original survey. This is more accurate than simply duplicating the survey records, because that cannot create a record with different characteristics from those that appear in the survey. Therefore, record duplication will simply create multiple records with identical characteristics, and combinations of traveler characteristics that do not appear in the original survey sample will never appear in the expanded sample no matter how large it is, whereas a synthetic sample will create records with characteristics that do not appear in the original sample. This will ensure that analysis zones that were thinly populated with survey respondents in the original sample will have a much more representative mix of traveler characteristics in the expanded sample and not be biased toward the characteristics of those travelers that happened to appear in the original survey sample.

Two other considerations relate to the application of a model estimated on data at one point in time to predict behavior in future years, as is typically done in planning studies. The first consideration is how to adjust travel times and costs for the various modes to correspond to future conditions. Highway travel times for future years should reflect any anticipated changes in highway congestion. Future costs are more problematical, because their effect on traveler decision making will depend on their value relative to the overall cost of living as well as changes in the income level of travelers over time. Typical practice is to consider that the cost and income variables in the model are expressed in real dollars (i.e., do not need to be increased to account for inflation). However, that is not to say that the cost of different modes will not change over time in real dollars. If general

income levels rise or fuel prices increase in real terms, then transportation operators will need to raise their prices to cover their higher costs of doing business and the cost of operating private vehicles will rise. Conversely, if transportation operators are able to achieve productivity gains or rising levels of air travel increase the traffic that they carry, allowing them to be more efficient, then they may be able to reduce their prices in real terms. Although these effects may tend to offset each other, the net effect is likely to vary by mode. Therefore, some thought should be given to assumptions about future travel costs and not simply assume that they will remain unchanged in real terms.

Historically, household incomes have increased in real terms over time, although over the past 30 years the distribution of household incomes has also changed, with the incomes of higher-income households increasing faster than that of lower-income households (U.S. Census Bureau 2006, Table A-3). Whether the effect of household income is explicitly included in the mode choice model or implicitly included in the coefficients of cost terms, some thought should be given to how to incorporate future growth in household income in the application of the model for future years. This is not a trivial matter. From 1995 to 2005 the average household income in the United States increased by almost 11% in real terms (U.S. Census Bureau 2006, Table A-1). This is equivalent to a reduction in the relative costs of different modes by at least that amount, which could easily have a greater effect on mode use than the type of transportation system enhancement that mode choice models are used to evaluate. Because higher income households use air travel more than lower income households, the real increase in the average household income of air travelers and the corresponding effect on airport access mode choice is probably even greater.

Pivot Point Analysis

Rather than use a disaggregate mode choice model directly to predict the change in mode shares as a result of some change in transportation service levels, it is possible to use the relevant model coefficients and the existing mode shares to predict the *change* in mode share for a given *change* in the explanatory variables. This has come to be known as the *incremental logit model* or *pivot point analysis* (the predicted mode shares are considered to pivot about the existing mode shares) (Kumar 1980). Another way to think about this type of analysis is to use the model coefficients and existing mode shares to determine the slope of the demand curve at the current values of the transportation service variables and mode use, and then calculate the change in mode share for a given movement along the demand curve corresponding to the change in the value of the transportation service variable (Meyer and Miller 1984).

In the case of MNL models (or binary logit models), the incremental logit equations are fairly straightforward and are given by Kumar (1980). The derivation of the corresponding equations for a NL model is somewhat more involved, owing to the existence of the scaling parameters and the more complex structural form of the model, but the same approach can be applied.

The advantages of this approach are two-fold. The first is that it eliminates any error in the predictions resulting from differences between the mode use predicted by the model at current values of the transportation service variables and the actual mode use. The second is that it only requires values for the model coefficients of the variables that change in value and not for the other variables or the ASCs. However, this is also a potential weakness of the approach. If the ASCs reflect some of the contribution of the transportation service variables to the predicted mode shares (perhaps owing to specification errors in the model or errors in measuring the transportation service levels), then those effects will be ignored in the analysis. Therefore, an alternative approach would use the full model, but apply the predicted change in mode use to the existing observed mode use.

Demand Elasticity

The concept of demand elasticity refers to the percent change in demand for a 1% change in some variable. Therefore, the demand elasticity with respect to the price for taxi use at an airport would express the percent change in taxi use for each percent change in fare levels. In the case of a MNL model with a linear utility function, it can be shown that the elasticity of the probability of choosing a particular mode with respect to a given variable in the utility function is given by:

$$\varepsilon_{ik} = \alpha_{ki} \cdot X_{ki} \cdot (1 - P_i)$$

where ε_{ik} is the elasticity of the probability of choosing mode i with respect to changes in the value of the explanatory variable X_k for mode i (X_{ki}), α_{ki} is the coefficient of X_k in the utility function for mode i, and P_i is the current probability of choosing mode i. In simple terms, this is saying that the elasticity is given by the product of the coefficient of the variable, the current value of the variable, and the probability of not choosing the mode. As the probability of choosing a particular mode increases, the elasticity of the probability of choosing that mode with respect to any variable becomes less.

However, this is of limited use because it is clear from the previous equation that the elasticity of demand varies with the value of the variable in question for every air party and with the probability of each air party selecting the mode in question at current values of all the explanatory variables. Therefore, elasticity is not a constant property of a given mode or a given situation, but varies with the values of the transportation service variables and with the market shares of the different modes. Nonetheless, for any given situation the

elasticity of demand for a given mode with respect to a given service variable can be calculated numerically, and this may be a useful thing to do to give planners and managers an easily understood tool to make quick assessments of the likely effect of any proposed change. The important caveat to ensure this is clearly understood is that any given elasticity value is only valid for the particular situation for which it has been calculated and will change as the situation changes. In particular, if changes occur in other modes the elasticity for the mode in question will change because changes in other modes will change the probability of choosing the mode for which the elasticity has been calculated.

CHAPTER THREE

REVIEW OF THE LITERATURE

AIR PASSENGER MODE CHOICE MODELS

The ability to predict how airport users will respond to changes in the service characteristics of the ground access modes serving the airport or the addition of new ground access services is clearly an essential part of any effective analysis of proposals to enhance the airport ground transportation system. In addition, airport ground access models play an important role in studies addressing how future air travel demand will be distributed among airports in a multi-airport region. The relative accessibility of airports serving a region is recognized as one of the key determinants of air passenger airport choice (in addition to the air service offered at the airports). Whereas early airport choice models simply used highway travel times as a measure of airport accessibility, later models have recognized that appropriate measures of airport accessibility need to account for the range of ground transportation services available and the proportion of airport users who choose different ground transportation modes for their travel to and from the airport.

Because airport ground transportation involves trips both to and from the airport, ideally what are required are airport ground access *and egress* models. However, in practice, most modeling efforts to date have only addressed airport access, and it has been assumed (often implicitly) that the reverse trip reflects a symmetrical pattern of mode use. Personal experience and a growing body of evidence suggests that this is not the case, at least on the basis of the behavior of individual air parties, but this report focuses primarily on airport ground access mode choice models, because those are the models that are generally available. The review of the literature undertaken as part of this study found no examples of prior studies that explicitly modeled airport ground egress travel behavior. The focus on ground access trips no doubt results primarily from the use of air passenger surveys as the source of data on which to base the development of airport ground travel mode choice models. Because it is much easier to survey departing passengers rather than arriving passengers, air passenger surveys have generally addressed the ground access trip that the respondent has just completed, rather than the egress trip that a respondent beginning their air trip will make on their return or the egress trip that a visiting air traveler made on their arrival in the area some time before. The issue of the difference between airport ground access and egress travel behavior is discussed later in this report.

Therefore, given the importance of understanding air passenger airport ground access mode use it is not surprising that there have been a number of studies over the years that have developed air passenger ground access mode choice models. One of the earliest efforts to develop a formal model of air passenger airport ground access mode choice was undertaken in the early 1970s (Ellis et al. 1974). This study used a MNL model, as did several other studies that developed air passenger ground access mode choice models over the next ten years (Leake and Underwood 1977; Sobieniak et al. 1979; Gosling 1984; Spear 1984; Harvey 1986). However, by the mid-1980s it was becoming recognized that some of the limitations of the MNL model could be addressed through the use of NL models (Ben-Akiva and Lerman 1985). One of the first applications of NL models to airport ground access mode choice was undertaken as part of a study of surface access to London Heathrow Airport (Howard Humphreys and Partners 1987), followed shortly thereafter by a study by Harvey (1988) that used a NL structure to develop an integrated model of airport choice and ground access mode choice for the San Francisco Bay Area. Subsequent air passenger ground access mode choice models developed for Boston, Massachusetts (Harrington et al. 1996; Harrington 2003); Portland, Oregon (*PDX Ground Access . . .* 1998); and airports in the southeast and east of England (Halcrow Group Ltd. 2002b) used a nested structure, whereas other studies continued to use MNL models to represent air passenger ground access mode choice (Tambi and Falcocchio 1991; Dowling Associates, Inc. 2002; Psaraki and Abacoumkin 2002). In addition to models that have exclusively addressed airport access mode choice, a number of recent studies have used NL models to represent air passenger airport choice, with airport ground access mode choice as a lower-level nest (Bondzio 1996; Monteiro and Hansen 1996; Mandel 1999; Pels et al. 2003). However, these models generally only include a single-level nest for the airport ground access mode choice process and thus are equivalent to MNL models from the perspective of ground access mode choice.

The technical details of many of these models have been reviewed by Lunsford and Gosling (1994) and later by Gosling et al. (2003). However, the level of detail reported in the literature for each of the models varies, with some authors only providing partial information on estimated parameter values or even on the independent variables included in the model. It is common to estimate separate sets of model parameters, or

even different model specifications, for different market segments, such as residents of the area versus visitors, or air travelers on business trips versus those on leisure trips. Some published articles describing these models only present the estimated values of the model coefficients for some of the market segments. This makes comparison of the different models difficult. However, detailed results are available for a number of recent models. The principal features of these models are briefly described in the following sections. More detailed documentation of each of these models is provided in Appendix D included in the web version only.

Atlanta Regional Commission Model

The Atlanta Regional Commission (ARC), the MPO for the Atlanta region, has developed an Airport Passenger Model (APM) to model air passenger trips to and from Hartsfield–Jackson Atlanta International Airport (H-JAIA) as a component of the overall regional travel demand modeling process (*Model Documentation* . . . 2005). The model was originally developed in 2003 using data from the H-JAIA Peak Week Air Passenger Survey performed in 2000 and was updated in 2006 for new income groups for 2000 (*Travel Demand* . . . 2006). The ARC Airport Passenger Model (ARC/APM) consists of two components: a trip generation/distribution model that assigns the total originating air passenger traffic at H-JAIA to regional TAZs and a mode choice model that predicts the ground access mode use of those air passenger trips. A subsequent step converts air passenger trips to vehicle trips for inclusion on the traffic assignment step of the regional transportation demand model. The model is one of the few examples (and the only one documented in this study) of a special-generator airport access mode choice model fully integrated into a regional travel demand modeling process.

The ARC/APM predicts air passenger and vehicle trips using four market segments: resident business, resident non-business, non-resident business, and non-resident non-business. The mode choice model considers five modes: air passengers dropped off by private vehicle, private vehicle parked at the airport for the duration of the air trip (termed drive self), rental car, transit, and taxi. Although not explicitly stated in the model documentation, it appears from the documentation that the transit mode includes the Metropolitan Atlanta Rapid Transit Authority rail and bus services, commercial shared-ride shuttle van services, and other high-occupancy shared-ride modes such as charter bus, whereas the taxi mode includes exclusive ride limousine services and hotel and motel courtesy vehicles, as well as conventional taxi use.

The basic form of the mode choice model is a NL model with a separate structure for trips by residents of the region from that for non-residents. The model does not take the type of ground access trip origin into account. Therefore, all visitors to the region are considered to include drop off by private vehicle and rental car in their choice set, whether or not they are staying with residents of the region and thus have someone who could drop them off at the airport or the need for a rental car during their visit. The explanatory variables consist of the travel times and costs for each mode. Separate variables are defined for in-vehicle, walk, and wait times. The transit in-vehicle times use the total in-vehicle time for the trip from the origin zone to the airport zone, transit walk times combine access, egress, and sidewalk times from the transit network, and the transit wait times combine the initial wait with any transfer wait times.

Boston Logan International Airport Model

This model was developed by the Central Transportation Planning Staff (CTPS) in Boston using a 1993 air passenger survey done at Boston Logan International Airport (Harrington et al. 1996; Harrington 2003). Separate sub-models were developed for resident business trips, resident non-business trips, non-resident business trips, and non-resident non-business trips. The two resident sub-models consist of a NL model, with separate nests for door-to-door modes (taxi and limousine) and automobile modes (drop off, short-term parking, long-term parking, and off-airport parking). There are four shared-ride public modes at the top level (regular transit, scheduled airport bus, the Logan Express service to off-airport terminals in the region, and the Water Shuttle between the airport and the downtown Boston waterfront). The visitor sub-models are MNL models and omit the long-term parking alternatives but add a hotel shuttle mode.

This model is particularly relevant to studies involving improved public transportation access to airports because it includes both a rail access mode, the Massachusetts Bay Transportation Authority (MBTA) regional rail transit system, and off-airport terminals, the Logan Express service operated by the Massachusetts Port Authority (Massport), the airport authority for Logan Airport. The MBTA Airport Station is adjacent to the airport and linked to the passenger terminals by a free shuttle bus service operated by Massport. Unlike many other airport access mode choice models, the CTPS model is also interesting in that it treats rental car use as an independent decision and excludes it from the mode choice decision process.

Chicago Airport Express Ridership Forecasting Study

In 2003, the Chicago Department of Transportation retained Resource Systems Group, Inc. and Wilbur Smith Associates to undertake a ridership and revenue forecasting study of a proposed Airport Express train service between downtown Chicago and O'Hare International and Midway Airports (Wilbur Smith Associates 2004). To identify the pattern of air passenger trip ends, travel party characteristics, and existing access mode use, and to understand how airport travelers

might change their access mode choice if the Airport Express train were available, two surveys of air travelers were undertaken by Resource Systems Group, Inc. at O'Hare and Midway Airports, an origin–destination survey and a stated preference survey (Resource Systems Group Inc. 2004). The origin–destination survey results were used to develop a profile of existing originating air passenger characteristics, including trip purpose, trip origin, and ground access mode use, as well as current and future trip tables that predicted the number of trips by market segment originating in each of 145 TAZs within the study area.

The stated preference survey interviewed 1,110 air travelers in the two airports, who were asked about details of their trip to the airport, and then asked to complete eight stated preference choice experiments in which they were presented with a choice between three trip modes, including the mode they had just used and the Airport Express train. The results of the stated preference survey were used to estimate a mode choice model that defined nine airport access modes: private vehicle parked at the airport for the duration of the air trip, drop off at airport by private vehicle, rental car, taxi, other private mode, Airport Express train, Airport Bus, Chicago Transit Authority train, and other public mode. The "other private mode" included limousine, hotel/motel courtesy shuttle, and shared-ride airport van service, whereas the "other public mode" included local bus, region train and bus service, and charter bus. The mode choice model used a NL form with a somewhat different nest structure for travelers on business and non-business trips, as shown in Figure 4.

The utility functions for each airport access mode included two continuous variables, total travel time and travel cost, in addition to alternative specific constants. The estimated coefficients for each of the two continuous variables within a given market segment were constrained to have the same value for each mode. Traveler income was not explicitly included in the model, but travelers were divided into two income categories on the basis of household income and separate travel cost coefficients estimated for each category. Although a single travel time variable was used in each utility function, weights were applied to various components of the total travel time that was used in the model estimation to account for different disutility of access, transfer, and waiting

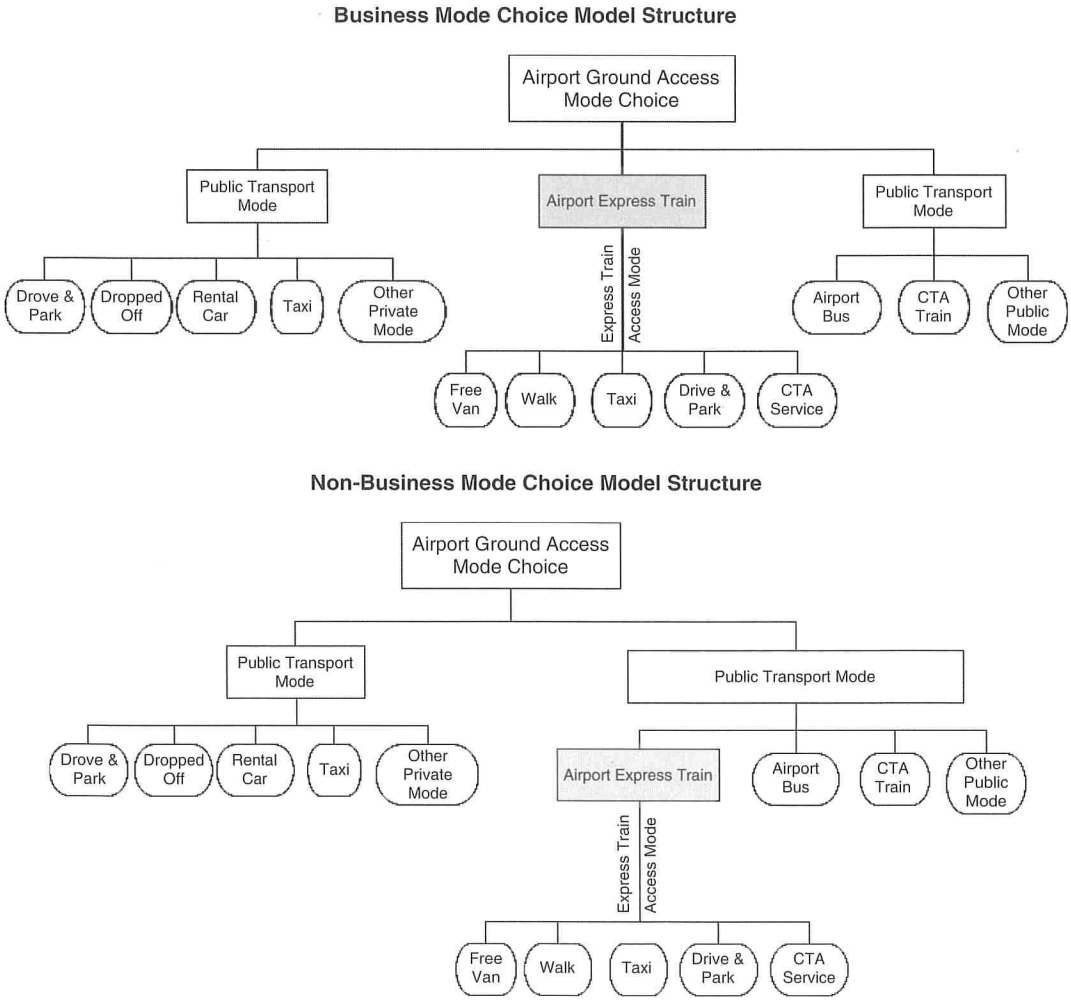

FIGURE 4 Chicago Airport Express mode choice model nesting structure (*Source:* Wilbur Smith Associates 2004).

time (as applicable) for each mode. The weights were determined by iteratively adjusting their value to obtain the best overall model estimation result. In addition to the two continuous variables, a dummy variable for the availability of baggage check-in at the downtown terminal was included in the Airport Express and Airport Bus modes, and a second dummy variable was included in the Airport Express mode for those passengers boarding at an intermediate station.

Separate model coefficients were estimated for business and non-business travelers. The same model coefficients were used for residents and non-residents of the Chicago region, although the available modes for these two market segments were different. After the model coefficients were estimated using the stated preference data, the model was calibrated to correspond to the mode shares for the study area obtained from the origin–destination survey data by adjusting several of the ASCs until the model predicted the observed mode shares from the study area.

The calibrated mode choice model was applied to forecast ridership and revenue for the Airport Express train for various service scenarios for 2009 and 2020, including two different fare levels, several different travel time assumptions for the service to O'Hare Airport, two different growth rates for off-peak highway travel time, and whether or not a free downtown shuttle or baggage check at the downtown terminal would be provided (Wilbur Smith Associates 2004).

Miami Intermodal Center Travel Demand Forecast Study

The Miami Intermodal Center (MIC) is being planned as a major transportation interchange facility located immediately to the east of the Miami International Airport (MIA) to provide an integrated terminal for several intercity transportation services, including Amtrak, Tri-Rail commuter rail, and Greyhound buses, as well as Metrobus and Metrorail transit services (*Miami Intermodal Center* . . . 1997). An APM (the MIC/MIA Connector) will link the MIC to the airport. Provision has also been made in the planning for future High Speed Rail and East–West Corridor rail lines as well as an Airport/Seaport Connector rail link. The MIC will also help accommodate growth of MIA by providing expanded airport landside facilities, including rental car and long-term parking facilities. As part of the planning for the MIC, a travel demand forecast was prepared by ICF Kaiser Engineers (1995) that incorporated an airport access mode choice model that was used to forecast ridership on the MIC/MIA Connector. The mode choice model was based on a model originally developed by KPMG Peat Marwick for a study for Newark International Airport in New Jersey.

Because of the large number of modes available at MIA and the complexity of the choices available as a result of the MIC project, the mode choice model was expanded to include the following nine modes: drop off by private vehicle, private vehicle parked for the air trip duration, rental car, taxi, limousine, premium transit, local transit, shared-ride van, and hotel courtesy shuttle. The model used a NL structure with the first five modes grouped into a nest called Non-Group modes and the other four modes grouped into a nest called Group modes. The model defined four market segments: resident business trips, resident non-business trips, non-resident business trips, and non-resident non-business trips.

The model has only three explanatory variables, apart from the ASCs: in-vehicle travel time, out-of-vehicle travel time (including waiting time and terminal time, such as walking from the parking lot to the airport terminal or returning a rental car), and travel cost. There is no consideration given to the effect of income differences in the model. The values for the coefficients for the continuous variables were not estimated from the air passenger survey data, but rather adopted from the values estimated for Newark International Airport in the original model with the same coefficient values being used for each market segment. Values for ASCs for each mode were estimated from air passenger survey data to fit the model predictions of mode use to the observed data.

Bay Area Rapid Transit–Oakland International Airport Connector Study

Since the 1970s, a number of studies have been undertaken by the Port of Oakland (the operator of Oakland International Airport), Bay Area Rapid Transit (BART), and other agencies to explore the feasibility of developing an APM connection to replace the current AirBART shuttle bus link between the airport and the Coliseum BART station located approximately 2.5 miles from the airport (*BART–Oakland* . . . 2002, Executive Summary). As part of on-going efforts to implement the Oakland Airport Connector, a Final Environmental Impact Report/Environmental Impact Statement (EIR/EIS) was completed and approved in March 2002. The analysis for the EIR/EIS included the development of an airport access mode choice model by CCS Planning and Engineering, Inc., that was applied to generate ridership projections for the Connector (*BART–Oakland* . . . 2002, Appendix B: Transit Ridership Procedures and Inputs). The mode choice model addressed both air passenger trips and airport employee trips, with the employee trips treated as a separate market segment. The general form of the model is a MNL logit model with air passenger trips divided into four market segments: resident business trips, resident personal trips, visitor business trips, and visitor personal trips.

Data on the air party characteristics for each market segment were obtained from the 1995 Air Passenger Survey undertaken for the Metropolitan Transportation Commission (MTC) at the three Bay Area airports (including Oakland International Airport), supplemented by surveys of AirBART passengers performed by CCS Planning and Engineering, Inc., in December 1999 and May 2000 as part of the study.

The model assigns airport trips among the following eight modes: private vehicle, rental car, scheduled airport bus, public transit, shared-ride van, hotel courtesy shuttle, taxi or limousine, and other. Public transit included both the use of BART by means of the AirBART shuttle (or the Connector in the future), as well as local transit bus service directly to the airport. The transit alternative for travelers with trip origins in zones near the airport was assumed to be local bus, whereas the transit alternative for those from more distant zones was assumed to be BART. The use of "other" modes was not explicitly modeled, but rather the use of those modes was assumed to remain constant from the mode share observed in the 1995 Air Passenger Survey.

The model utility functions included the following six variables: highway travel time, travel time by rail transit, travel time by bus transit, walking distances, waiting times, and travel costs, although not all variables applied to each mode. The distinction between rail transit travel time and bus transit travel time allowed the analysis to consider the effect of replacing the AirBART shuttle bus with the planned APM, as well as the different level of service between BART and local bus. Household income was included in the model by dividing the costs for personal trips by the household income in thousands of dollars raised to the power 1.5. This adjustment was not applied to business trips as it was considered that business travel decisions are unaffected by income because business travelers are usually reimbursed for travel expenses. The model coefficients for the continuous variables were adopted directly from an earlier airport ground access mode choice model for the Bay Area developed by Harvey (1988). The values of the ASCs were then estimated to fit the model to the mode use data from the 1995 MTC Air Passenger Survey.

The mode choice model market segment for airport employees included only two modes, private vehicle and public transit, and is discussed further in the following section on airport employee travel choice.

Portland International Airport Alternative Mode Study

Soon after the Boston Logan model was developed, a similar modeling effort was undertaken in Portland, Oregon, as part of a ground access study for Portland International Airport, jointly undertaken by the Port of Portland and Metro, the regional MPO, with the assistance of Cambridge Systematics, Inc. (Bowman 1997; Cambridge Systematics 1998; *PDX Ground Access . . .* 1998). The primary purpose of the model was to forecast the potential ridership on potential ground access enhancements, including a planned extension of the Portland MAX (Metropolitan Area Express) light rail system to the airport. An air passenger survey was done at the airport that combined a revealed preference survey that examined air passengers' actual mode use and a stated preference survey that was designed to determine travelers' preferences for modes that were not then available, namely light rail, express bus, and shared-ride transit (it is unclear from the documentation how this was defined).

An initial model estimation was done by Cambridge Systematics (Bowman 1997; Cambridge Systematics 1998) that jointly estimated MNL models using both the revealed preference and stated preference data for the same four market segments as the Boston Logan model. Separate ASCs were estimated for each mode for trips originating within the Portland metropolitan area (termed internal trips) and those originating outside the metropolitan area (termed external trips). Two different sets of model parameters were estimated for each market segment, reflecting different assumptions for the ASCs for the light rail and express bus modes. The models were subsequently revised by Metro staff to combine some of the choice alternatives and recalibrate the models by adjusting the ASCs (*PDX Ground Access . . .* 1998).

In addition to the development of a mode choice model, a review of the experiences of other U.S. airports with a range of airport ground access strategies was undertaken as part of the overall study of alternative airport access modes (Coogan 1997). This report included statistics on the ground access mode shares of various airports that had implemented ground transportation services similar to those being considered for Portland, as well as a discussion of the operational experience of those airports with the ground transportation services and the lessons that might be applicable to the Portland situation. Although there was no explicit comparison of the results of the mode choice analysis with the experience at other airports, this study put the results of the mode choice modeling into a larger context and served to provide some assurance of the likely validity of the modeling results.

San José International Airport Model

This model was developed by Dowling Associates (2002) and was designed to estimate the ridership on a planned APM to connect the airport to a nearby Santa Clara Valley Transportation Authority light rail line. The model was estimated using data from an air passenger survey performed at the airport for the Bay Area Metropolitan Transportation Commission in 1995 and supplemented with the results of stated preference surveys that were conducted as part of the study to determine how air passenger mode choice might be influenced by the availability of the APM and to compensate for the limited number of users of the light rail line in the 1995 survey sample. The model used a MNL form with separate coefficients for the same four market segments used in the Oakland International Airport–BART Connector model, as well as an airport employee segment. Each air passenger market segment included six modes: private vehicle, rental car, scheduled airport bus, shared-ride door-to-door van, taxi, and public transit. In addition, the visitor market segments included hotel shuttle. The model implementation allowed for up to four different public transit routes from any

given analysis zone, and the model used separate coefficients for bus travel time and rail travel time. In addition, a separate ASC was used for those routes that included the use of the APM to reflect the greater attractiveness of this link as determined from the stated preference survey. The model is very similar in structure and form to the model used for the Oakland International Airport–BART Connector analysis and used the same approach of adopting the model coefficients from Harvey (1988) and estimating ASCs.

The mode choice model market segment for airport employees included only two modes, private vehicle and public transit, and is discussed further in the following section on airport employee travel choice.

Toronto Air Rail Link Revenue and Ridership Study

In May 2003, Transport Canada issued a Request for Business Case for a public–private partnership to develop an Air Rail Link between the Toronto Lester B. Pearson International Airport and Toronto Union Station (*Request for Business Case* . . . 2003). In preparation for the Request for Business Case, a revenue and ridership forecasting study was undertaken in 2002 (Halcrow Group 2002a). The study included the conduct of a stated preference air passenger survey and the development of a mode choice model to predict the diversion of airport access trips from existing modes to the proposed new rail link. The stated preference survey was carried out in February 2002 in the terminal departure lounges and collected data on the air party characteristics, ground trip origin, and ground access mode for the current trip. Some 807 respondents were identified as potential air rail link users and completed a stated preference questionnaire, the results of which were then used to estimate a set of binomial logit mode choice models, each of which models the choice between an existing mode and the planned rail link.

Air travelers using hotel bus or rental car to access the airport were excluded from the diversion analysis, because users of a hotel bus were assumed to have a door-to-door service that was effectively free, whereas those using a rental car were assumed to require the car for other purposes during their visit and thus not consider the use of other modes. The mode choice model relationships use three continuous variables: the in-vehicle travel time on each mode, the service headway for the mode, and the travel cost involved in using the mode. In addition, the utility function for the rail link includes two dummy variables: one that indicated whether the air traveler was accompanied (whether by other members of the air travel party or by well-wishers) or traveling alone and one indicating whether the air traveler(s) intended to check any bags. The model structure does not directly consider the type of trip origin. However, the approach of developing separate diversion models for each existing access mode indirectly addresses some of these effects, because air passengers being dropped off by private vehicle would largely have begun their trip from a private residence, whereas those using taxi or airport bus would be more likely to have begun their trip from a hotel or place of business. The model utility functions also do not consider the household income of the air travelers.

ASCs were initially included in the model utility functions; however, these were found to be not statistically significant and were dropped from the model. This is surprising given the relatively simple form of the utility functions and the absence from the model of such factors as household income and the access time involved in reaching the rail link station. Separate model coefficients were estimated for four market segments: resident business, resident non-business, non-resident business, and non-resident non-business.

In addition to estimating a formal mode choice model, the study included a benchmark comparison analysis that examined the mode share of existing airport rail links in 24 cities in the United States, Europe, and Australia. This analysis developed cross-sectional regression relationships that expressed the rail mode share in terms of a series of market and geographical characteristics, such as the percentage of air passengers with central city origins, the distance of the airport from the central city, and the ratio of rail travel time to taxi travel time from the city center. These relationships were then used to predict the corresponding rail mode share for Toronto using the same regional characteristics. The resulting range of rail mode shares (which varied with the characteristic chosen) was compared with the results of the formal mode choice modeling process, to provide a reality check on the modeling analysis.

United Kingdom South East and East of England Regional Air Service Study Air Passenger Surface Access Model

As part of the South East and East of England Regional Air Service (SERAS) study undertaken for the U.K. Department of Transport, Local Government and the Regions, a set of surface access models was developed that included an air passenger mode choice model, an airport employee trip distribution model, and an airport employee mode choice model (Halcrow Group 2002b). The air passenger mode choice model is a NL model that covers 12 defined ground access modes and has separate coefficients and model structures for the following six market segments:

- U.K. business passengers on domestic trips,
- U.K. business passengers on international trips,
- U.K. leisure passengers on domestic trips,
- U.K. leisure passengers on international trips,
- Non-U.K. passengers on business trips, and
- Non-U.K. passengers on leisure trips.

The 12 ground access modes consist of several different types of rail links, including a dedicated express rail service

(such as the Heathrow Express service from Central London to Heathrow Airport), London Underground, and coach connections to nearby mainline rail stations, as well as private automobile (both drop off and park), rental car, taxi, local bus, and charter and intercity coach. The mode choice structure uses a multi-level tree to account for the complex pattern of public modes and alternative rail services, with the modes grouped in a different tree structure for each market segment. A representative choice structure for one of the market segments is shown in Figure 5, and details of the choice structure for the other market segments are included in Appendix D, which can be found in the web version of this report. The utility functions for each mode use a generalized cost approach that considers travel time, out-of-pocket costs, and time penalties for interchanges, with all costs converted to equivalent minutes of travel time.

The airport employee mode choice model is discussed further in the following section on airport employee travel choice.

Other Recent Studies

In addition to the foregoing nine models, the survey of airport authorities, MPOs, and consultants discussed in the next chapter identified several other recent airport access modeling studies that are not discussed in any detail in this report owing to limited technical documentation.

In 2002, the North Central Texas Council of Governments (NCTCOG), together with the Dallas/Fort Worth International Airport, Dallas Area Rapid Transit, and Fort Worth Transportation Authority completed a Major Investment Study to evaluate potential rail links to the Dallas/Fort Worth International Airport (DMJM Aviation, Inc. 2002). As part of the study, ridership estimates were prepared for a range of project alternatives that included shuttle bus links to existing commuter rail lines near the airport as well as direct commuter rail service to the airport and extension of a regional light rail system to the airport. The demand modeling was undertaken by the NCTCOG using its regional travel demand

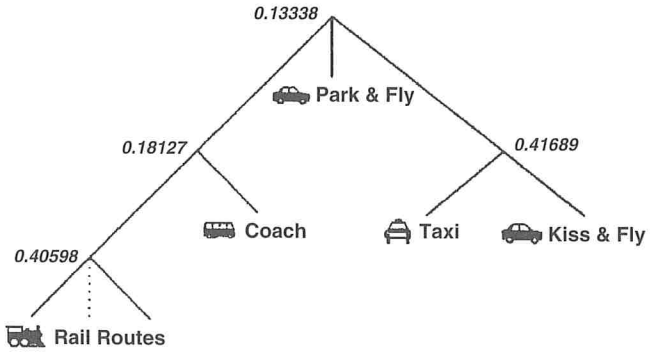

FIGURE 5 SERAS model—Representative mode choice structure: U.K. Business Passengers on International Trips (*Source:* Halcrow Group 2002b).

model that incorporates an airport trip special-generator model (*Dallas–Fort Worth Regional . . .* 2007). This model generates home-based non-work and non-home-based trips corresponding to the forecast air passenger traffic at the airport. These trips are then added to other regional trips in each category to determine the overall distribution of regional trips before mode choice analysis and trip assignment to the regional transportation network. Airport employment is handled through the regular home-based work trip generation process. The mode choice models do not treat airport trips differently from other trips in each trip category (Cambridge Systematics 2005).

Following the 9-11 attacks on the World Trade Center in New York, the Lower Manhattan Development Corporation was established to rebuild Lower Manhattan and create a sense of place that would revitalize the economy of the area. To improve the transportation links to Lower Manhattan, the Lower Manhattan Development Corporation, in cooperation with the Metropolitan Transportation Authority, the Port Authority of New York & New Jersey, and the New York City Economic Development Corporation, undertook a feasibility study of alternative ways to provide a new rail link between Lower Manhattan and suburban commuter markets in Long Island and John F. Kennedy International Airport (Parsons/SYSTRA Engineering 2004). Following an identification and screening process of potential project alternatives, two alternatives were selected for further analysis: a new tunnel under the East River between Lower Manhattan and Brooklyn and the use of the existing Montague Street tunnel and realignment of existing subway services. Both alternatives have a number of potential variants. As part of the on-going environmental analysis of these alternatives, a more detailed ridership analysis is being undertaken to evaluate the likely use of the proposed service by airport travelers under the various project alternatives being considered.

In 2005, the Aéroports de Montréal undertook a feasibility study for establishing a rail shuttle between the city center of Montréal and Montréal–Trudeau International Airport (Guilbault et Associés 2005). The rail link would operate largely over existing tracks of the Canadian National Railway from the Central Station in Montréal to the vicinity of the airport. The study involved a stated preference survey of 1,000 air passengers at Montréal–Trudeau International Airport and a further 200 air passengers at Montréal–Mirabel International Airport, the results of which were used to develop a mode choice model to predict the likely ridership on the rail shuttle at varying train frequencies and fare levels.

In July 2000, the Sacramento Area Council of Governments published the findings of a study of transit access to the Sacramento International Airport (*Sacramento International . . .* 2000). This study reviewed the findings of prior studies addressing the feasibility of extending the Sacramento light rail system to the airport through a developing area to the north of the city known as the Natomas Basin. The study recommended

that the Sacramento Regional Transit District pursue more detailed analysis of the feasibility of an extension of the light rail system to North Natomas and the airport and to preserve the right-of-way identified in prior studies. In October 2001, the Regional Transit District initiated the Downtown/Natomas/Airport Transit Alternatives Analysis/Draft Environmental Impact Statement and Report project. This included the development of a travel demand forecasting methodology (DKS Associates 2002), the conduct of a combined revealed preference and stated preference survey, and the development of an air passenger mode choice model (DKS Associates 2004).

AIRPORT EMPLOYEE TRAVEL CHOICE

In contrast to air passenger ground access mode choice, there has been very little attention paid to airport employee ground access mode use in the literature. In one of the earliest studies to explicitly address airport employee access trip patterns, Dunlay (1978) developed a model of airport employee vehicle trips based on information on employee shifts from a survey of airport employees at Dallas/Fort Worth International Airport. However, the model did not address mode choice and assumed that the mode split found in the survey (which was almost exclusively private vehicle use anyway) would remain constant, or at least could be adjusted from exogenous data if the model were to be applied in another situation. Instead, the objective of the model was to predict access and egress vehicle traffic flows by time of day, reflecting that airport employees do not enter or leave the airport exactly at the start and end of their shift.

A later study by Boyle and Gawkowski (1992) examined the changes in ridership on the Q3 bus in Queens, New York, when the bus route was extended to better serve employment areas at John F. Kennedy International Airport, and service was subsequently improved to provide higher frequency and earlier and later hours. Because a large part of the increase in ridership was comprised of employees at the airport, it follows that this improvement in service resulted in a change of journey-to-work mode split. However, the study did not attempt to collect data on what other modes airport employees were using either before or after the improvement in service and did not develop a formal model of airport employee access mode choice.

A subsequent paper by Riccard (1995) described an airport employee commute program at Boston Logan International Airport that was instituted to encourage employees to use alternatives to single-occupant vehicles for their journey to work. The paper contains an extensive discussion on factors that affect airport employee decisions on how to get to and from work as well as a large amount of data on airport employee commute patterns at the airport, but no formal modeling of the mode choice process.

In general, it appears that most studies addressing airport employee mode choice have simply used the journey-to-work component of the regional travel demand model for the area, considering the airport as no different from any other employment center. However, three specific models of airport employee travel have been identified in the literature. A special-purpose airport employee mode choice model was developed for the Greater London region as part of the U.K. SERAS study (Halcrow Group 2002b) and airport employee market segments were included in two mode choice models that were developed to analyze planned APM connections, one between the Oakland International Airport and the Coliseum station of the BART system (*BART–Oakland . . .*, Appendix B: Transit Ridership Procedures and Inputs 2002) and one between the San José International Airport and a nearby light rail station of the Santa Clara Valley Transportation Authority (Dowling Associates 2002). However, none of these models was estimated directly on airport employee travel data. The SERAS model was based on one developed for a different study covering the area to the south and west of London Heathrow Airport that included all journey-to-work travel, not just airport employees. The Oakland International Airport and San José International Airport models adapted regional travel demand models for home-based work trips, but calibrated these to airport employee mode use data. All three models are discussed in more detail in chapter six and the relevant sections of Appendix D (web version only).

CHAPTER FOUR

USE OF AIRPORT GROUND ACCESS MODELS IN AIRPORT PLANNING

SURVEYS OF AIRPORTS, PLANNING AGENCIES, AND OTHER ORGANIZATIONS

To better characterize the current state of practice with airport access mode choice models, as well as to identify models that may been developed for specific studies but not reported in the published literature, a survey was undertaken of airport authorities, regional and state planning agencies, federal agencies involved in airport or surface transportation planning, airport consulting firms, selected universities and other research organizations, and relevant industry associations. The survey enquired about recent airport ground transportation studies undertaken by the responding organization and whether these involved the use of formal models of airport ground access mode choice. The survey also enquired about respondents' perceptions of the usability of such models, as well as their awareness of other organizations that have experience with the use of these models.

A list of potential survey recipients was developed and reviewed with the Project Panel. This list was comprised of all U.S. large hub and medium hub airports in 2005 (defined by the FAA as those enplaning more than 1% and 0.25% of total U.S. enplaned passengers, respectively), as well as the eight largest Canadian airports, together with a sample of 47 MPOs and the aeronautics or aviation agencies for each state. Three of the state aviation agencies (Hawaii, Maryland, and Rhode Island) are also responsible for operating large or medium hub airports included in the sample and were not surveyed separately as state agencies. The sample of MPOs comprised all of those responsible for regions with a Metropolitan Statistical Area population in 2003 of one million or more, because those were felt to be the most likely to become involved in airport ground transportation planning. Although the hub size definition used by the FAA is based on enplaned passengers rather than originating passengers (who use the ground access system), those airports with a high proportion of connecting passengers are generally the larger airports that also generate a large amount of ground access trips.

In addition, the survey recipients included 42 consulting firms involved in airport planning studies and 17 academic and other researchers who were known to have an interest in airport ground transportation studies, as well as selected key staff in four federal agencies involved in airport ground transportation issues: the FAA, FHWA, FTA, and Volpe National Transportation Systems Center. The survey was also sent to three industry organizations representing airport operators, airport consultants, and airport ground transportation operators.

In addition to the survey recipients on the mailing list, an e-mail request was sent to the chairs of several TRB committees with a scope relevant to airport ground transportation or transportation modeling issues. The e-mail described the scope of the study and asked them to forward the information to the members and friends of their committees and invite any with relevant experience to participate in the survey. This generated a number of additional survey responses.

Four slightly different survey questionnaires were developed reflecting the different concerns and needs of the various types of organizations included in the survey. In addition to the online versions of the survey, the four questionnaires were prepared as Microsoft Word documents that could be downloaded from the TRB website and completed off-line. Survey recipients were given the option of responding to the survey by downloading the appropriate version of the questionnaire and returning it by e-mail, fax, or mail. The four questionnaires are found in Appendix A.

A memorandum from the ACRP staff officer responsible for the project was sent by e-mail to each survey recipient requesting their assistance with the project by participating in the survey and providing a link to the online survey and the Word version of the questionnaire. The memorandum requested survey recipients to respond within approximately 3 weeks of the initial requests. A reminder e-mail message was sent at the end of this period to those survey recipients who had not responded and several follow-up messages were sent over the subsequent weeks.

Survey Response

As of July 2, 2007, 107 responses representing 105 different organizations were received. The composition of the responses is shown in Table 1.

The overall response rate to the survey was approximately 43%. The response rate varied across the different types of organizations, from a response rate for large hub airport authorities, MPOs, and airport planning consultants of around 50% to a response rate for research organizations of approximately 30%. The response rate for state aviation agencies

TABLE 1
SURVEY RESPONSE

Type of Organization	Sample Size	Sample Responses	Other Responses	Total Responses
Airport Authorities	26	13		
Large hubs	35	15		
Medium hubs	8	3	1	
Other (Canadian)				
Subtotal	69	31	1	32
Metropolitan Planning Organizations	47	23	2	25
State Aviation Agencies	47	16		16
Federal Transportation Agencies	7	3		3
Airport Planning Consultants	42	21	3	24
Research Organizations	17	5	2	7
Industry Organizations	3	0		0
Total	232	99	8	107

was approximately 35%, whereas that for medium hub airports and federal agencies was approximately 43%. One MPO forwarded the survey request to its state DOT, which does the transportation modeling for the MPO. The resulting response has been included with the MPO responses.

The overall response to the survey was believed to be reasonable, given the specialized nature of the topic and the diverse composition of the sample. It is likely that those organizations with the most experience with airport ground access modeling would have been more inclined to respond, and indeed many respondents provided valuable information. However, the relatively small number of responses in any category limits the ability to draw any statistically robust conclusions from the survey results for different types of organizations. Nevertheless, it is believed that the survey provides a reasonable profile of the extent to which airport ground access mode choice models are used in airport landside planning and some indication of how this varies across different types and sizes of organizations.

SURVEY FINDINGS

In view of the limited number of survey responses for each type of organization, the survey findings are presented for all respondents combined, although the role of each type of organization is somewhat different. Where there appear to be significant differences between the responses to a given question across the different types of organizations this is discussed in terms of the actual count responses.

Number of Airport Ground Access and Airport Choice Studies

Of the 105 organizations responding to the survey, 57 (53%) reported that they had sponsored, undertaken, or participated in studies over the past ten years that included some analysis of airport ground access mode choice. The proportion of different types of organizations that reported some involvement in ground access studies varied considerably. Perhaps not surprisingly, most large hub and equivalent Canadian airports (13 of the 14 responding), airport consulting firms (20 of 23 responding), and researchers (6 of the 7 responding) reported involvement in studies of this nature. In the case of airport consulting firms and researchers, this may reflect that those organizations with experience of this type of study would be more likely to respond to the survey. MPOs and state aviation agencies reported a much lower level of involvement in such studies, with only 8 of the 24 MPOs that responded to the survey and only one of the 16 state aviation agencies reporting any involvement.

The survey responses identified 103 specific studies, together with some references to other studies that were too vague to identify the specific studies in question. Some responses mentioned air passenger surveys. However, these are not considered analytical studies in the sense intended by the question and are not included in the count. Several of the respondents appeared to be referring to the same study and after eliminating duplicate references the responses identified 85 separate studies, ranging from airport master planning studies through feasibility studies for improved airport ground transportation services to academic studies of air passenger ground access mode choice.

A significant number of these studies have not previously been reported in the literature, at least in a way that would allow a typical literature search to identify them as being relevant to airport ground access mode choice analysis. Therefore, the survey has been very valuable in identifying a broader range of airport ground access studies than is generally reported in existing bibliographic reviews of airport ground access issues.

The survey also asked respondents whether their organization has undertaken or participated in studies over the past ten years that have included some analysis of air passenger airport choice. Of the 105 organizations responding to the survey, 37 (35%) reported some involvement in such studies. Respondents identified 32 separate studies. Although it appears from the titles of the studies that several may not be airport choice studies in the sense intended by the question, the responses identified a number of studies that have not been previously reported in the literature.

Use of Analytical Models

Respondents were asked to state whether any of the studies involving some analysis of airport ground access mode choice made use of formal analytical mode choice models. Of the 57 respondents reporting such studies, 34 (60%) indicated that the studies involved such models and specifically identified 52 of the 85 separate studies previously reported. Thus, it appears that the use of formal mode choice models in airport ground access studies is quite widespread.

The survey also asked whether any of the studies involving analysis of airport choice made use of formal analytical models of airport ground access mode choice as a factor in airport choice decisions. Of the 37 respondents reporting such studies, 15 (41%) indicated that the studies included the use of such models and specifically identified 16 separate studies. However, three of these studies were updates of a regional transportation planning process by the same organization using the same model.

Respondents who indicated that airport ground access studies included the use of formal analytical models of mode choice were asked about the source of air passenger survey data used in the development of the models. Of the 34 respondents reporting studies involving the use of such models, 23 (68%) indicated that the models utilized data from surveys performed specifically for model development and an equal number indicated that the models used data from surveys performed for other purposes. Multiple responses were possible from a given respondent, because their responses could cover more than one study or a given study could use data from more than one survey.

The survey asked those who reported involvement in airport ground access studies that made use of formal analytical models of mode choice whether reports from any of these studies are available on their organization's website. Only five respondents indicated that this was the case, one airport authority, two MPOs, and two universities. Further investigation established that the airport authority website was an intranet site that is not accessible to the general public. The survey also asked whether reports on the air passenger survey data used in the development of the mode choice models are available on the responding organization's or another organization's website. Only five respondents (not the same five) indicated that this was the case. Thus, it appears that the majority of the studies identified in the survey are not readily available from the Internet and direct follow-up with the sponsoring organizations would generally be necessary to obtain documentation on these studies.

To determine if the use of analytical mode choice models may have increased in recent years, as well as to identify experience that may not have been reported because it occurred before the ten-year period mentioned in the earlier questions, respondents from airport authorities and MPOs were also asked if their organization had undertaken or commissioned studies prior to the last ten years that made use of formal analytical models of airport ground access mode choice. Of the 55 organizations responding to this question, 9 (16%) indicated that they had and 29 (51%) indicated that they had not. A further 17 were not sure whether they had or not. Therefore, of the 38 respondents who knew whether such studies had been done, only approximately 24% reported the use of such models in earlier studies. This is not significantly different from the percentage reporting the use of such models in studies undertaken during the past ten years (13 respondents out of 56 organizations, or approximately 23%), particularly because those who were not sure or did not answer the question may well be less likely to have undertaken such studies than those who knew either way. Therefore, there does not appear to have been a significant increase in the use of analytical models in recent years.

Satisfaction with Existing Models

The survey asked those respondents who reported the use of formal analytical models of airport access mode choice how they would characterize the current state of practice with such models based on their organization's experience. Of the 34 organizations that reported experience with the use of such models, 19 (55%) indicated that current models were adequate for their needs, 12 (35%) indicated that current models are not reliable enough, 3 (10%) indicated that current models are too complex to use, and 10 (30%) indicated that they are too costly to use (multiple responses were allowed).

Although on its face this suggests a generally high level of satisfaction with the current state of practice, it is noteworthy that seven of the eight airport authorities and all five of the MPOs reporting the use of such models indicated that current models are adequate for their needs, whereas only 5 of the 13 consulting firms reporting involvement in studies using such models indicated that current models are adequate. Because in many cases the studies using such models are performed by consultants rather than the airport authority or MPO staff, and the consultants may well be reluctant to share any concerns about the adequacy of the analysis with their clients, this may suggest that the apparent confidence in the current

preference studies have been done to develop model coefficients for the planned modes or services that do not yet exist, and thus are not reflected in surveys of actual mode choice.

Functional Form of the Model

Although the MNL model continues to be used in airport access mode choice models, it is becoming accepted that the NL model is generally a more appropriate formulation. The airport ground transportation system consists of a large number of different modes and sub-modes, which are likely to be viewed by a traveler as having very different substitutability. Therefore, a traveler trying to decide between parking in a close-in parking lot or a remote parking lot with a shuttle bus connection to the airport terminal is not likely to care very much about differences between bus fares and taxi rates. Conversely, a traveler trying to decide between the lower cost but longer travel time of taking transit to the airport and the higher cost but greater convenience of a taxi or shared-ride van is unlikely to care very much about differences in parking rates between on-airport and off-airport lots. It is precisely the effect of these different substitution rates that the NL model is designed to reflect. Because the private vehicle generally accounts for the majority of airport ground access trips at most airports, at a minimum an air passenger mode choice model should nest the private vehicle choice alternatives for residents of the region (drop off and park for the duration of the trip).

Although no generally accepted practice has yet emerged for how to structure the nests of a NL model, this is largely determined by the characteristics of the different modes because the primary purpose of using a NL model is to allow higher rates of substitution between modes that have similar characteristics. Therefore, it would appear logical to group private vehicle modes in one nest, with different parking options as a second-level nest, group exclusive ride on-demand modes (taxi and limousine) together in a second first-level nest, and group shared-ride scheduled modes (public transit, scheduled airport bus) together in a third first-level nest, possibly with different transit options (e.g., rail and bus) as a second-level nest. It is not clear where the door-to-door shared-ride van would best fit in this structure, as a separate mode at the top level, in the on-demand nest with taxi and limousine, or in the shared-ride nest with the scheduled modes. This may be an issue to resolve empirically by exploring which option gives the best fit to the data. Alternative access modes to scheduled services can also be included as lower-level nests to each mode.

Rental car and hotel shuttle use by non-residents is best modeled outside this choice process, because use of both modes is determined by factors that are largely independent of the service levels of other modes. Rental car use is often determined by local travel needs other than the airport egress and access trip. Therefore, visitors to the region may rent a car even if they are staying at a nearby hotel that has a free shuttle to and from the airport.

The form of the utility functions for each choice alternative will generally be a linear combination of explanatory variables with their associated coefficients. However, some variables are best entered in the utility function as an inverse or ratio. For example, the service headway of scheduled modes, which is a direct measure of average waiting time, is the inverse of the service frequency. The effect of household income may best be entered in the utility function by expressing direct travel costs as a ratio of the cost to some function of the per capita or total household income. Therefore, higher-income travelers will be less influenced by cost than lower-income travelers.

Some model developers have attempted to reflect nonlinearity in the effect of some variables (such as service frequency or income) through the use of the logarithm of the variable value in the utility function. However, there are theoretical problems with this approach and great care is needed when introducing logarithms into the specification of terms in the utility function. Although a logarithmic transformation may approximate some other function (such as the inverse) over part of the data range (with appropriate coefficients), it can differ significantly at lower and higher values. However, it can be precisely at these values that the effect of the variable on traveler behavior is most important. Therefore, it is critical to consider whether the logarithmic transformation of the variable best reflects the nonlinear effect that is desired compared with some other function.

Survey Data Used in Model Development

Although air passenger or airport employee surveys are sometimes performed primarily (or entirely) to support development of airport access mode choice models, more commonly model development makes use of surveys conducted for other purposes. However, because such models, particularly air passenger models, require detailed information on air traveler characteristics and factors likely to influence their choice of access mode, it is highly desirable that if a survey will be (or even might be) used later to support development of an airport access mode choice model, the survey questions are reviewed by modeling specialists before the survey is performed to ensure that key questions are not omitted that would later compromise the ability to develop a reasonable model.

Among the factors that are often omitted from air passenger and employee surveys, but are critical for model development, is information on household income and household composition. It is self-evident that traveler decisions between alternative access modes that offer a trade-off between travel time and cost will be influenced by their perceived value of time (even if they do not think of the decision in those terms). Because one cannot meaningfully ask survey respondents to

state their value of time, the functional form of the model needs to include some measure of household income so that the values of time implied by the model coefficients will vary by income. However, as noted elsewhere in this report, willingness to pay to save time is influenced not only by the total household income, but also by how many people that income has to support. Although these questions are often omitted as intrusive or even of little relevance for other purposes to which the survey data will be put, experience has indicated that reasonable responses can be obtained if the questions are asked in the right way.

Another factor that affects airport access travel decisions is the time that a traveler begins a trip to or from the airport, both in terms of the time of day and (in the case of departing air passengers) the time remaining before their scheduled flight departure. This information can also be useful in the case of shared-ride van services to determine how much lead time the operator required to schedule other pickups, because this can affect the overall access time experienced by the traveler. Similarly, with scheduled modes, this information can provide an indication of how much margin of error travelers allow in their travel plans to avoid missing scheduled services.

Transportation Service Data

In addition to data on the characteristics of the airport travelers, mode choice model development and application requires data on the transportation service levels of the different modes. These will include travel times, fares or costs, service frequencies of scheduled modes, any walking distances involved, and network connectivity issues such as the number and type of anticipated transfers required between different services. The extent to which different explanatory variables have been included in various existing models is discussed later in this chapter.

Generally, these data are obtained from transportation network models or from published information by transportation providers, rather than by asking survey respondents. There are two reasons for this. The first is that transportation service-level data are required for all the modes included in the model and it would be too cumbersome to ask each survey respondent for their perception of the value of these service levels for every mode, and indeed they may have no idea of the details of those modes that they did not use. The second reason is that for any application of the models, different values of at least some of the transportation service levels are typically assumed, whether to reflect expected future values or to model the effect of changing the ground access system in some way, and therefore the values used in the model application can be established in a consistent way to those used in the model development.

To the extent that the traveler perception of the service levels of the various modes differs from the values used in model estimation, it is implicitly assumed in the modeling that the estimated values of the model coefficients convert the values of the service levels used in the modeling to the values perceived by the travelers. Therefore, the model coefficients serve two purposes: to adjust the values of the service levels used in the modeling to the values perceived by the travelers and to express those perceived values in terms of their contribution to the overall perceived utility of each alternative. Because it is highly likely that many airport travelers have only limited information about many of the alternatives included in the modeling, and the perception of the transportation service levels relative to the values used in the modeling may vary widely across the respondents to surveys used to develop the models, this is likely to have a significant impact on the overall ability of the model to explain the observed choices. Unfortunately, the question of how well airport traveler perceptions of the service levels of the different modes conform to the values used in modeling is one that has been largely ignored in the literature on modeling practice.

Because it is necessary to determine the transportation service levels faced by each travel party included in the modeling process, it is normal practice to define a system of analysis zones and assign the ground access trip origin of each respondent in an airport traveler survey to the appropriate analysis zone. To provide a reasonable level of precision for the ground access service levels, in particular travel times, these analysis zones cannot be too large. A fairly common practice is to use the TAZs defined for the regional travel demand model developed for general transportation planning in the region.

The relevant regional transportation planning agency will generally be able to provide the highway travel times and transit service levels (travel times and fares) from each TAZ to the airport from the regional transportation network model. The extent to which these travel times can be expressed in terms of their components (e.g., walking time, waiting time, and in-vehicle time) or different values can be provided for different times of day or different days of the week is likely to vary from agency to agency. In general, regional travel demand modeling tends to be based on average weekday conditions and distinguish between peak and off-peak travel times. However, it is not uncommon to only model one peak period (typically the morning peak).

To develop the appropriate transportation service data for the other airport access modes, such as shared-ride van services, taxis, and any scheduled airport bus services, it will be necessary to obtain the relevant service information (travel times, fares, and schedules) from the transportation providers and convert these to the analysis zone system being used. Given the number of analysis zones typically used, this can be a significant task. This task can become more complicated if some time has passed since the airport traveler survey that is being used to develop the model was performed, because transportation providers may have changed

their service levels in the interval and do not always maintain good records of past service levels. One potentially useful source of information on transportation provider service levels may be the ground transportation section of the airport website, where this provides the relevant level of detail, or websites of the transportation providers. Ideally, this information would be archived whenever an airport traveler survey is done, so that it can be referred to later if the data changes; however, unfortunately this is not often done. An historical archive of some website content is available through the Internet Archive, a nonprofit organization that maintains an online web archive called the Wayback Machine (http://www.archive.org). However, this only provides the content of web pages and cannot recover information in underlying databases that may have been accessed by web pages.

Travel times by services such as taxi and limousine will generally be the same as other highway modes. Taxi fares that are distance-based can be calculated from the meter rates and highway distances obtained from the regional travel demand model network data. Shared-ride van travel times will typically depend on the number of other parties that have to be picked up after picking up the party in question and the additional travel involved. Because this will vary from air party to air party, it will be necessary to make some assumptions about the average travel times experienced from a given analysis zone. In the case of fixed-route services, such as scheduled airport bus or rail modes, consideration needs to be given to how airport travelers will access the relevant stop or station where they will board the service. In the case of nested mode choice models, the access mode to the fixed-route service may be treated as part of the choice process and will require separate travel times and costs for the different access alternatives (e.g., walk, drop off by private vehicle, taxi, and public transit). Where this secondary access choice process is not explicitly modeled, assumptions will need to be made about the access time and cost to be included in the utility function of the primary mode.

MODES INCLUDED IN MODEL

The modes to be included in an airport access model are largely determined by the modes available at the airport, although not all the modes available at an airport may be included in a given model. In particular, some modes may be combined in the model or excluded from the analysis with users assumed to be captive to the mode. The modes included in nine recent airport access mode choice models described in chapter three are shown in Table 2, together with the type of model used and the nature of the data from which the model was estimated.

Rental car and taxi are generally available at all airports. Most of the larger airports will also have some form of limousine (black car) service and some door-to-door shared-ride van service. Public transit service is likely to be very location-specific. Representation of the use of private vehicles needs to distinguish between air passengers who are dropped off at the airport and those who park the vehicle at or near the airport for the duration of the air trip, because there are significantly different costs involved and being dropped off at the airport generates additional vehicle travel for the return trip. Whether or not those dropping off or picking up air passengers park the vehicle for a time at the airport is less important and generally not addressed in mode choice models. In any event, the decision of whether or not to park is likely to be determined by factors not typically included in ground access mode choice models, such as whether the vehicle driver arrives at the airport earlier than intended.

Whether or not to model the choice of parking location by those parking for the duration of their air trip is a more difficult question. Most airports offer a choice of parking facilities, with less expensive options often involving a shuttle bus ride to reach the terminal. In many cases there are also privately operated off-airport parking lots that provide a shuttle bus service to the airport. These various facilities typically charge different daily rates. Thus, the choice of which facility to use affects the cost of the ground access trip as well as the travel time involved in the access trip. Where these choices are not explicitly included in the model, the travel time and cost assumed for parking for the duration of the air trip needs to reflect the proportional use of the different parking options, which will vary with the air trip duration.

The degree to which it is necessary to identify specific public transportation services depends to an extent on the purpose of the model. Because in general public transit tends to attract a fairly small mode share at most U.S. airports, except at those with an extensive fixed-rail system serving the airport (e.g., the Washington Metro at Ronald Reagan National Airport), it may be sufficient to consider this a single mode and assume that travelers will use the best path through the network. However, where the model will be used to evaluate specific services or analyze the market for the introduction of a new mode, it will then be necessary to identify the alternative services in more detail so that ridership on specific services can be calculated. The model developed for Boston Logan International Airport discussed earlier included rail transit, the Logan Express scheduled airport bus service from off-airport terminals in the region, and a Water Shuttle ferry that ran between the airport and downtown Boston. However, the model does not distinguish between the different Logan Express terminals. In contrast, the model developed for the SERAS study in the United Kingdom includes an explicit representation of several different types of rail services to be able to model how changes in specific rail services affect not only the overall mode share of rail but how those using rail would choose between the different services.

Two important issues to be addressed are how to incorporate rental car use and the use of a courtesy shuttle bus service

TABLE 2
MODEL TYPE AND MODES INCLUDED IN RECENT AIRPORT ACCESS MODE CHOICE MODELS

	Airport or Study								
	ATL	BOS	CHI	MIA	OAK	PDX	SJC	YYZ	UK
Year Model Developed	2002	1996	2004	1995	2001	1997	2002	2002	2002
Model Structure									
Binomial logit								*	
Multinomial logit		*			*	*	*		
Nested logit	*	*	*	*					*
Estimation Data	RP	RP	RP/SP	RP	RP	RP/SP	RP/SP	RP/SP	RP
Modes in Model									
Private vehicle—drop off	*	*	*	*		*		*	*
Private vehicle—park	*		*	*		*		*	*
Private vehicle—park ST		*							
Private vehicle—park LT		*							
Private vehicle—park OA		*							
Private vehicle—combined					*		*		
Rental car	*		*	*	*	*	*		*
Taxi	*	*	*	*	*	*	*	*	*
Limousine		*		*					
Shared-ride van				*	*	*	*		
Scheduled airport bus		*			*		*	*	
Express bus from OAT		*	*			*			*
Transit (all services)	*				*			*	
Transit (rail)		*	*	*		*	*		*
Transit (bus)				*			*		*
Intercity coach									
Airport express train			*						*
Intercity rail/coach links									*
Ferry (water shuttle)		*							
Hotel shuttle bus/van		*		*		*	*		*
Charter coach									
Other private modes			*						
Other public modes			*						

Model: ATL = Hartsfield–Jackson Atlanta International Airport (*Travel Demand . . .* 2005).
BOS = Boston Logan International Airport (Harrington 2003).
CHI = Chicago O'Hare International Airport, Chicago Midway Airport (Resource Systems Group 2004).
MIA = Miami International Airport (ICF Kaiser Engineers 1995).
OAK = Oakland International Airport (*BART–Oakland . . .* 2002).
PDX = Portland International Airport (*PDX Ground Access . . .* 1998).
SJC = San José International Airport (Dowling Associates 2002).
YYZ = Toronto Lester B. Pearson International Airport (Halcrow Group 2002a).
UK = United Kingdom SERAS study (Halcrow Group 2002b).

Notes: RP = revealed preference data; SP = stated preference data; ST = short-term (i.e., associated with air passenger drop off); LT = long-term (i.e., park on airport for duration of air trip); OA = off-airport; OAT = off-airport terminal (e.g., Logan Express service at Boston)—includes inter-airport transfer coach (London).

from nearby hotels in the model. Visitors to the region may rent a car for local travel quite independently of their airport egress and access travel decisions. Those staying at hotels with courtesy shuttle bus service are likely to use that service, because it is usually free, unless they rent a car for other reasons. Therefore, it would appear appropriate to model rental car use by visitors first and then assign visitors staying at hotels with courtesy bus service to that mode if they are not assigned to a rental car.

In some cases residents of the region may also rent cars for their airport access trip, particularly if they live some distance from the airport and will be away for some time on their air trip. Local rental car agencies may not charge a drop-off penalty for returning the car to the airport, and two one-way rentals may be much less expensive than parking their own car at the airport for the duration of their trip or using other modes. Therefore, a rental car can be included in the regular choice set for resident travelers. In general, it will have a very low probability of being chosen owing to the high fixed cost, but will become more attractive for the type of trip described earlier.

EXPLANATORY VARIABLES

Existing models differ widely in terms of the explanatory variables used in the utility functions, as well as how those variables are defined. The variables included in the nine airport access mode choice models discussed in the previous section are shown in Table 3.

All existing models include some measures of travel time and cost. However, the extent to which travel time is separated into its components (walk time, waiting time, in-vehicle travel time, and time involved in private vehicle access to public transportation services) varies. The model developed for Boston Logan International Airport estimated separate coefficients for in-vehicle time, walk and wait time (combined as out-of-vehicle travel time), and automobile access time to public transportation. The models developed for Oakland International Airport and San José International Airport to evaluate proposed APM links (*BART–Oakland* . . . 2002; Dowling Associates 2002) used separate coefficients for walk distance, waiting time, and in-vehicle time in private vehicles, buses, and light rail, although these were adopted directly from Harvey (1988). The use of separate coefficients for in-vehicle time in the different modes was intended to capture differences in the perceived comfort and convenience of rail compared with bus, as well as between private vehicle and transit. The models developed to estimate ridership on the proposed Chicago Airport Express train (Resource Systems Group 2004) used a weighted travel time, with the weight for access time, waiting time, and transfer time adjusted incrementally to obtain the best model fit. Both the Boston Logan model and the U.K. SERAS model included fixed penalties for transfers on the public transit system. The coefficient of the variable for the number of transfers in both models can be thought of as measuring the perceived disutility of a transfer in terms of the equivalent additional riding time on a non-stop service. The SERAS model distinguished between different types of transfer, such as cross-platform or those involving a level change.

In contrast, the model developed for the Portland ground access study (Bowman 1997; Cambridge Systematics 1998; *PDX Ground Access* . . . 1998) combined the different components of travel time into a single variable for total travel time without weighting any of the components. The model developed by the Atlanta Regional Commission included separate coefficients for highway travel time, transit in-vehicle time, waiting time, and walk time, although the values of these coefficients were adopted from other models and not estimated for the Atlanta region. Similarly, the model developed for the Miami Intermodal Connector project distinguished between in-vehicle time on all modes and the combination of waiting and terminal time (the time required to access the zone centroid in the transportation network), although this model also adopted coefficients from another model for a different region.

Cost and Income

Not unreasonably, most models combine costs into a single variable, although the Boston Logan model defined different cost variables depending on the income of the traveler and whether the employer was paying the cost of a business trip. However, this was simply a way to obtain different cost coefficients for each case. Several models have divided the cost by a function of the household income, although there is no consistency in what function was used.

The Boston Logan model (Harrington et al. 1996; Harrington 2003) divided respondents who paid their own travel expenses into two income categories (low and high) and estimated separate travel cost coefficients for each income category as well as for a third category of respondents whose travel expenses were paid by their employer. The Portland ground access study model (Bowman 1997; Cambridge Systematics 1998; *PDX Ground Access* . . . 1998) divided the travel costs incurred by air passengers by the natural logarithm of the household income, although this was not done for the automobile operating cost for drop-off trips.

The Oakland Airport Connector model (*BART–Oakland* . . . 2002) and the San José International Airport Model (Dowling Associates 2002) divided the travel costs for personal trips by the household income raised to the power 1.5, but did not do this for business trips.

Although each of these approaches will ensure that higher-income travelers (at least those paying their own expenses in the case of the Boston Logan model and those

TABLE 3
EXPLANATORY VARIABLES INCLUDED IN RECENT AIRPORT ACCESS MODE CHOICE MODELS

	Airport or Study								
	ATL	BOS	CHI	MIA	OAK	PDX	SJC	YYZ	UK
Continuous Variables									
Off-peak highway time	*								
Travel time (private vehicle)					*		*		
In-vehicle time (all modes)		*		*				*	
In-vehicle time (transit)	*								
In-vehicle time (rail transit)					*		*		
In-vehicle time (bus transit)					*		*		
In-vehicle time + walk time									*
Out-of-vehicle time[a]		*							
Total travel time (all modes)						*			
Weighted travel time[b]			*						
Wait time + terminal time[c]				*					
Wait time/headway	*				*		*	*	*
Walk time	*								
Walk distance					*		*		
Auto access time to transit		*							
Number of transfers		*							
Interchange penalties									*
Drop-off driver time						*			
Driving distance									*
Travel cost (all modes)		*	*	*	*	*	*	*	*
Private vehicle cost	*								
Drop off vehicle operating cost						*			
Transit fare	*								
Taxi fare	*								
Household income					*	*	*		
Dummy variables									
Air party size		*							
Baggage check-in			*						
Employer pays cost		*							
Flights/year		*							
Household income		*							
Luggage/checked bags		*						*	
Non-residence trip origin		*							
One-person travel party								*	
Use of intermediate station			*						

Model: ATL = Hartsfield–Jackson Atlanta International Airport (*Travel Demand . . .* 2005).
BOS = Boston Logan International Airport (Harrington 2003).
CHI = Chicago O'Hare International Airport, Chicago Midway Airport (Resource Systems Group 2004).
MIA = Miami International Airport (ICF Kaiser Engineers 1995).
OAK = Oakland International Airport (*BART–Oakland . . .* 2002).
PDX = Portland International Airport (*PDX Ground Access . . .* 1998).
SJC = San José International Airport (Dowling Associates 2002).
YYZ = Toronto Lester B. Pearson International Airport (Halcrow Group 2002a).
UK = United Kingdom SERAS study (Halcrow Group 2002b).

[a] Out-of-vehicle time on Boston model combined waiting time and walking time (access, transfer, and egress) as appropriate for the mode.

[b] Weighted travel time in Chicago model combined in-vehicle time and egress time with a weighted sum of access time, transfer time, and waiting time.

[c] Terminal time in Miami model used the regional travel demand model zonal terminal times that represent the additional travel time required to reach the TAZ centroid from the actual trip origin.

making personal trips in the case of the San José International Airport model) will be less sensitive to travel cost than lower-income travelers, clearly the effect on travelers of a given income level varies significantly. It is most unlikely that they all correctly reflect sensitivity to income, and those that simply classify travelers into two income categories obviously can only approximate the effect. Indeed, common sense suggests that total household income is only part of the story and the effect of household income must depend in part on the size of the household. There is clearly a huge difference between a single person making $100,000 per year and a family of six making the same annual income.

A related issue that is generally ignored is the difference of purchasing power of a given income level between residents of the area in question and visitors. Perceived values of time are likely to depend on the level of discretionary income of individual travelers, which in turn is affected by the cost of living in their home region rather than that of the region where the airport is located. Therefore, it can be expected that visitors to a region from another region where the cost of living is significantly different are likely to have different perceived values of time for a given level of per capita household income than residents of the region where the airport is located. This issue has important implications for the transferability of mode choice models from one region to another, as discussed further in chapter seven.

In view of the lack of any well-established practice regarding how best to incorporate traveler income into airport ground access mode choice models, this would seem to be a useful topic for future research.

Travel Time Components

As discussed earlier, it is widely recognized that the different components of travel time are likely to have a different disutility per minute. This is particularly true for waiting time and walking time (although this may be measured by distance rather than time). There are two approaches to addressing this. The first is to weight the various components of travel time differently before combining them into a single travel time variable for the purpose of model estimation. The second is to estimate separate coefficients for each component. The latter is preferable, because assumptions for the relative weights of different travel time components based on the experience of other models may not be appropriate for the particular situation being modeled. Some models estimate separate coefficients for travel time on different modes. This has the advantage over the use of a single travel time variable for all modes that if the relative perceived disutility of different modes varies by length of trip, this will be reflected in the estimated values of the coefficients. Only relying on ASCs to reflect differences in the perceived disutility of different modes implicitly assumes that any differences are independent of the length of the trip, which is highly unlikely.

One issue that arises with scheduled modes is how to handle the waiting time involved. There is an extensive literature on how travelers value the disutility of waiting time relative to travel time, particularly in the context of transfers between different transportation modes or services (e.g., Mohring et al. 1987; Moreau 1992; Small 1992; Chang and Hsu 2001; Hensher 2001; Lam and Small 2001). The general consensus is that waiting time has a higher disutility (higher perceived value of time savings) than in-vehicle travel time, although the ratio between the two appears to vary with circumstances, typically in the range between 1.5 and 2.5.

Some authors have argued that because the schedule is published and people will arrive a certain amount of time before departure, waiting time is effectively independent of service headway. Others have used half the service headway as the average waiting time. This is commonly referred to as schedule delay, and it is argued that although the traveler may only wait at the bus stop or station for few minutes, they have a time that they would prefer to have departed and the difference between that time and the time that they actually depart is part of the disutility of travel, even if they are actually doing something else. In the case of airport access and egress trips, this argument is quite persuasive. Airport travelers will generally take an earlier bus or train if one is not leaving at the time they would prefer to have departed, because taking a later service may cause them to miss their flight or, in the case of airport employees, be late for work. However, arriving early at the airport has relatively little value, because they are likely to just spend longer waiting in the gate lounge or for their shift to start. Similarly, in the reverse direction, any time spent waiting at the airport for the next departure from the airport is generally not usable for other activities apart perhaps from reading.

The changes in the amount of time that air travelers have to allow for airport security screening since the events of 9/11 adds a further complication to how passengers may perceive the disutility of arriving at the airport earlier than they would prefer. On the one hand, any additional time provides something of a buffer against unexpected delays in clearing security. On the other hand, if passengers are already concerned about the amount of time that they have to spend at the airport because of the need to allow enough time for security delays, they may be even more intolerant of having to arrive at the airport earlier than they would prefer owing to the waiting time while traveling to the airport.

A related issue arises from the schedule dependability when a connection is involved. If the trip to the airport involves connecting between two (or more) scheduled services, then the traveler needs to consider the possibility that if one service runs late, they may miss their planned connection and have to wait for the next departure on the subsequent segments of the trip. Therefore, the perceived schedule reliability may play an even more important role than the actual waiting time involved according to the schedule. Ironically,

the less the waiting time involved in making connections according to the published schedule, the higher the probability that the traveler may miss the connection, unless the outbound services at the connecting point wait for the inbound services to arrive. This issue is not unique to airport ground access trips and arises with all scheduled transportation services.

The issue of travel time dependability is not restricted to waiting time. One advantage of rail access modes is that the travel times involved are not subject to the variability that can affect highway travel times resulting from accidents or unexpected congestion. Thus, it might be expected that the perceived disutility of each minute of travel time on a rail mode might be different from that of each minute of travel time on highway modes. Because the disutility of time spent on different modes is also affected by the level of comfort offered by the mode and other factors, such as perceptions of personal safety, it is not obvious whether on balance the higher reliability of rail modes could be offset by other factors. The use of separate coefficients for travel time on each mode allows the model estimation process to determine the relative perceived disutility. However, the more model coefficients that have to be estimated, the larger the dataset needs to be to obtain statistically significant estimates of the coefficients.

Other Variables

In addition to travel time and cost, several models have attempted to include other variables believed to influence air passenger ground access mode choice, including the amount of luggage that an air party has, familiarity with the airport, and whether the traveler or someone else is paying for the trip. Some models, such as the Boston Logan model (Harrington et al. 1996; Harrington 2003), have also included air party size as a separate variable. However, to the extent that some costs, such as transit fares, vary with the number of people in the travel party, it is generally better to address the effect of air party size through the calculation of the travel costs of the different modes, rather than try to handle this through a separate variable, which simply adds a fixed amount to the disutility of the affected modes irrespective of the actual value of the travel costs involved.

Those models that have included variables reflecting the amount of checked baggage, such as the Boston Logan model (Harrington et al. 1996; Harrington 2003), the Toronto Air Rail Link model (Halcrow Group 2002a), and the earlier work by Harvey (1988) on which the models for Oakland International Airport and San José International Airport were based, have generally found this to be a significant factor in explaining model choice. It would therefore seem desirable to include this in any airport access mode choice model, particularly if the model is to be used to study proposed services that include off-airport baggage check-in, where the attractiveness of that capability will depend on the amount of baggage that an air party has. However, some thought needs to be given to the appropriate specification of a baggage variable in the post-9/11 environment, in which there are strict limits on carry-on bags. As a result, passengers may well check a bag, even though it is not large enough to present any limitation to their use of public transportation. The widespread adoption of wheeled bags over the past decade has also reduced the difficulty of carrying bags on public transportation services.

Not surprisingly, the issue of whether any of the travel costs will be paid by someone other than the traveler was found to be a significant factor in mode choice in the Boston Logan model (Harrington et al. 1996; Harrington 2003), the only model where this has been included. Although this is not a factor that can be independently forecast and simply applies to a particular subset of respondents in a given survey sample (generally those on business trips), its inclusion in a model improves the model fit to the data and helps reduce any bias in the coefficients of other variables that might result from not considering this issue. Similarly, the Boston Logan model found that familiarity with the airport and available ground transportation services, as measured by the number of flights from the airport in the past year by the survey respondents, was a significant factor in explaining mode choice of residents of the region. Although frequency of use of an airport may be a useful indicator of familiarity with alternative ground transportation services, it is likely to be a fairly inaccurate one. Some frequent travelers may make no effort to learn about the alternative transportation options, whereas some infrequent (or even first-time) users of the airport may have researched their different options or sought advice from more frequent users. Therefore, ideally, air passenger surveys would attempt to obtain a better indication of the familiarity of respondents with alternative ground transportation services. However, it is far from clear how to do this effectively and this is an important aspect for further research, because it is self-evident that travelers will not choose services that they do not know exist.

Implied Values of Time

The ratio of the travel time coefficient to the cost coefficient can be interpreted as the implied value of time (strictly of travel time savings). These values for eight of the mode choice models described in Tables 2 and 3 and discussed in more detail in Appendix D (web only version) are summarized in Table 4. The implied travel time values for the U.K. SERAS model are not included in the table because they are expressed in pounds and were derived using a different methodology; therefore, they are not directly comparable to the U.S. experience. Because separate coefficients were estimated for the two Chicago airports in the Chicago Airport Express study, Table 4 presents the implied values of time for each airport separately.

TABLE 4
IMPLIED VALUES OF TIME FROM RECENT AIRPORT ACCESS MODE CHOICE MODELS

	Airport or Study								
	ATL	BOS	ORD	MDW	MIA	OAK	PDX	SJC	YYZ
Year of Cost Data	a	1993	2003	2003	b	c	1996	c	2002
Travel Times ($/hour)						d		e	f
Highway time		g	h	h			i		
Resident business trips	15	11	33	63	78	15	19	15	53
Resident non-business trips	13	17	25	22	78	16	29	10	29
Non-resident business trips	16	40	33	63	78	15	19	15	71
Non-resident non-business trips	12	13	25	22	78	16	30	10	34
Transit in-vehicle time		j				k		k	
Resident business trips	11	26	33	63	78	11	19	11	53
Resident non-business trips	9	7	25	22	78	12	29	7	29
Non-resident business trips	12	15	33	63	78	11	19	11	71
Non-resident non-business trips	9	9	25	22	78	12	30	7	34
Travel time (other cases)		l	m	m		n	o	n	
Resident business trips		22	92	82		20	24	20	
Resident non-business trips		38	55	57		19	37	12	
Non-resident business trips		40	92	82		20	24	19	
Non-resident non-business trips		13	55	57		19	39	11	

Model: ATL = Hartsfield–Jackson Atlanta International Airport (*Travel Demand . . .* 2005).

BOS = Boston Logan International Airport (Harrington 2003).

ORD = Chicago O'Hare International Airport (Resource Systems Group 2004).

MDW = Chicago Midway Airport (Resource Systems Group 2004).

MIA = Miami International Airport (ICF Kaiser Engineers 1995).

OAK = Oakland International Airport (*BART–Oakland . . .* 2002).

PDX = Portland International Airport (*PDX Ground Access . . .* 1998).

SJC = San José International Airport (Dowling Associates 2002).

YYZ = Toronto Lester B. Pearson International Airport (Halcrow Group 2002a).

[a]Coefficients for time and cost adopted from other models (date unspecified).

[b]Coefficients for time and cost adopted from another model (date unspecified).

[c]Coefficients for time and cost adopted from Harvey (1988), 1995 cost data.

[d]For household income (only applies to non-business trips) of $75,000/year.

[e]For household income (only applies to non-business trips) of $55,000/year.

[f]Canadian dollars.

[g]Private vehicle drop off, costs not reimbursed, low income (undefined).

[h]Weighted travel time, low household income (less than $100,000/year).

[i]For household income of $50,000/year.

[j]Costs not reimbursed.

[k]Rail transit.

[l]Private vehicle drop off, costs not reimbursed, high income (undefined).

[m]Weighted travel time, all modes, high household income ($100,000/year or more).

[n]Bus transit.

[o]For household income of $150,000/year, all modes.

In addition to the implied values of time, Table 4 shows the year for which the cost data were obtained where this is known. Because the implied value of time is obtained from the ratio of the travel time coefficient to the cost coefficient, it is expressed in dollars of the year for which the cost data were assembled from which the model was estimated. In cases where the travel time and cost coefficients were adopted directly from other models, the value of time is expressed in dollars of the year for which the cost data used in estimating those models were assembled.

For those models where household income was included in the cost term of the utility function or different cost coefficients were estimated for different income categories, the implied value of travel time is a function of income (or varies by income category). In those cases where the values of time vary with income the values shown in Table 4 have been calculated for specific household income levels.

Because the different models were estimated using cost data for different years, the values of time are not directly comparable. Furthermore, for those models where the implied value of time is a function of household income, the values shown in Table 4 have not been calculated for comparable household income levels. Even so, it is clear from Table 4 that the variation in implied value of time across the different models is much greater than can be explained by either the different year for which the cost data were obtained or differences in the household income used to calculate the implied value of time. Given the differences in model structure and explanatory variables included in the model, this is hardly surprising. Including other terms than travel time and cost in the utility functions, or changing the way that travel time is defined in the model, will change the estimated values of the travel time and cost coefficients and hence the implied values of time. However, this has important implications for the ability of the models to predict how airport travelers will respond to changes in travel time and cost of airport access modes. If other terms in the model utility functions (such as dummy variables or ASCs) are accounting for part of the perceived disutility of travel time or cost for a particular mode, the contribution of those terms to the overall disutility of the mode will not change when the values of travel time or cost are changed in a given application of the model, resulting in an incorrect prediction of the impact of the change on perceived disutility and hence on predicted mode use.

MARKET SEGMENTATION

As noted earlier, although some early models considered more limited market segmentation, it is now widely recognized that at a minimum separate airport access mode choice models should be developed for at least four market segments corresponding to residents of the region being modeled versus visitors to the region, with each segment further split into business and non-business (or personal) trips. Almost all of the recent models developed in the United States have used this approach, although the model developed for the United Kingdom the SERAS Study (Halcrow Group 2002b) to analyze surface access to airports in the London region included two additional market segments to distinguish between domestic and international trips by U.K. residents. Although this model distinguished between U.K. residents and non-U.K. residents, rather than residents of the London region and visitors to the region, the distinction is less critical than it might at first appear. Distances in the United Kingdom are such that many U.K. residents will travel to the London airports by surface modes for international trips, whereas visitors to the United Kingdom will fly in to the London airports, even if their final destination is elsewhere in the country. The inclusion of a U.K. domestic market segment accounts for travel between London and the rest of the United Kingdom. Even so, this segmentation is problematical on a number of counts, and if the distinction between domestic and international travel is considered to be important (as it might well be in the United States as well as the United Kingdom), then it would probably be desirable to distinguish between international and domestic visitors to a region as well as international and domestic travel by residents of the region, giving eight market segments rather than the six used in the SERAS study.

Although the distinction between business and personal trip purposes is widely followed, air travel forecasting practice often also makes a distinction between what is usually termed vacation travel and visiting friends and relatives travel. The factors that influence the choice of where to stay (a hotel versus a local residence) as well as the airport egress and access travel options are quite different for visitors in the two categories. This distinction is less important for residents of the region, because their airport access trip is generally unaffected by what they are going to do at the other end of their trip.

The distinction between business and personal trips is largely a reflection that travelers on business are typically not paying their own travel costs. However, it does not always follow that business travelers are less concerned about cost than non-business travelers. The airport access mode choice model developed for Boston Logan International Airport by the CTPS (Harrington et al. 1996; Harrington 2003) distinguished between business travelers paying their own out-of-pocket costs from those whose travel costs were paid by their employer. This was handled by including a separate variable in the model utility function, but it could equally well (perhaps better) be handled by defining a separate market segment.

One important consideration in choosing the number of market segments to include in a model is the implications for the number of survey responses required to obtain reliable estimates of the model coefficients. Somewhat oversimplified, the more market segments that are defined the larger the sample size needed to estimate the model. This is not always true, because a poorly specified model may need a larger data sample size to achieve a desired level of confidence for the

model coefficients; therefore, adding another market segment may actually improve the model fit with a given data sample size if indeed that better reflects differences in the underlying behavior of the travelers. However, consideration also has to be given to the number of travelers in each market segment. A market segment with very few travelers will be difficult to model with any degree of confidence without a very large data sample, unless a stratified sample is somehow obtained that ensures an adequate number of responses in the data sample for each defined market segment.

MODEL PERFORMANCE

The issue of model performance is one that has largely been ignored in the literature, apart from the simplistic approach of reporting the level of significance (*t*-statistics) of the model coefficients and the overall goodness-of-fit of the model. The latter is usually expressed by the likelihood ratio, a statistical measure of overall fit of the model to the data that is quite meaningless to most users of the models. However, as suggested by Gosling (2006), what really matters is not how well the model fits the data from which it has been estimated, because the nature of the model estimation process largely forces this to be fairly good (that after all is the whole point of model estimation). Rather, what matters is how well the model predicts the airport ground access mode choice behavior when conditions change, such as the transportation services levels are improved (or degraded) or a new service is introduced. Even the stability of the model coefficients over time is an important concern if the model is to be used for forecasting (as they almost always are).

Unfortunately, there is very little discussion of these aspects in either the general literature on airport access mode choice modeling or the technical documentation of existing models. Some academic studies have selected a holdout subset of the data that they can then use to test how well the estimated model explains this subset. However, although this is better than no test at all, it still does not address many of the concerns identified previously, such as the effect of changing the transportation system or the stability of the model coefficients over time.

This issue is not unique to airport access mode choice models and there is very little literature on how well most travel demand models perform over time or when conditions change. There is a growing interest in this issue by the FTA in the context of the modeling used to support the Federal New Starts capital grant program (U.S. Federal Transit Administration 2006) and the term "reference-class forecasting" has started to come into use to describe a forecasting method that is based on the development of a so-called "outside view" of a particular project on the basis of information from a class of similar projects (Flyvberg 2005, 2007; Flyvberg et al. 2005). This approach involves placing the project in a statistical distribution of outcomes from a class of similar projects. Although the concerns that have motivated the development of reference-class forecasting are broader than simply the performance of travel demand models themselves and have as much to do with how those models are used, including the input assumptions on which forecasts are based, the approach is directly applicable to airport ground access mode choice modeling, particularly where the motivation for the development of these models is to forecast ridership on proposed new airport access links or services. The benchmark comparison analysis that was undertaken as part of the modeling for the Toronto Air Rail Link described in chapter three represents an example of this approach.

This suggests that monitoring the performance of the airport ground access system after the introduction of new services or transportation links should be a part of the project funding, so that adequate resources are available to do the necessary ongoing data collection and analysis after the project is complete, and indeed that the requirement to undertake this monitoring should be a condition of the project funding. Only by collecting data on the use of all of the ground access modes on an ongoing basis after a new service or link is opened can the changes in mode use be compared with the predictions of the mode choice models during the project planning stage and the performance of the models assessed.

However, although improved models are clearly desirable, as is a better understanding of the likely reliability of existing models; even an inaccurate model may be better than no model at all. The range of transportation alternatives that comprise the airport ground access system at most airports and the myriad traveler decisions that result in the observed pattern of access mode use are sufficiently complex that it is highly unrealistic to attempt to determine the likely effect of any significant change in the system by intuition alone. A well-constructed model is better than a guess. Even so, it is important to give appropriate consideration to likely sources of forecast error in any model application and undertake sensitive analysis to explore the possible effect of potential error in both the modeling and forecast assumptions on the model predictions. Potential sources of error include omission or incorrect representation of important explanatory variables, incorrect representation of the mode choice process implicit in the model structure, and optimism bias in selecting future values of explanatory variables. One useful approach to assessing the likely reliability of a model is to undertake a back-casting analysis that applies the model to explain observed behavior in the period before that for which the model was developed. This is particularly useful if significant changes occurred in the airport ground transportation system during that period, but may also shed light on the ability of the model to reflect the effect of changes in real costs and income levels over time.

CHAPTER SIX

AIRPORT EMPLOYEE MODE CHOICE

As discussed in the literature review in chapter two, the topic of airport employee ground access and egress mode choice has received much less attention in the literature than that of air passengers, and only one study was identified that described an airport access mode choice model developed to account for airport employee access mode choice behavior. In the case of airport employees, airport access trips are more commonly referred to as journey-to-work trips. However, these trips will be referred to as airport access trips in the following discussion for consistency with the treatment of airport access travel by air passengers.

As with air passengers, discussion of airport employee access mode choice behavior should really address both access and egress travel. However, unlike air passengers, airport employee egress mode use is likely to be the same as their access mode use. If they drive to work by private vehicle, then that constrains their choice mode for the return trip. Similarly, if they use public transportation for the journey to work, they do not generally have a private vehicle available for the return trip. Although situations may arise on an individual basis from time to time in which airport employees travel to work one way and return home another (e.g., they may come to work by public transportation but get a ride home from a co-worker), it can be expected that the effects of these irregular commute patterns will generally cancel each other out in the overall mode split.

Airport employee trips can account for a large share of the ground access trips generated by an airport, particularly for large airports that have a wide range of support activities, including air cargo handling, aircraft maintenance, and airline crew bases. An earlier TCRP study (Leigh Fisher Associates 2000) assembled data for a sample of airports on air passenger traffic and the estimated average number of daily employees working at the airport. These data are shown in Table 5, together with the ratios of average daily employees to average daily enplaned passengers and average daily originating passengers. The first ratio indicates the relationship between the number of airport employees and the overall level of airport activity, whereas the second ratio indicates the relationship between the number of airport employee airport access person-trips per day and the number of air passenger ground access person-trips per day, assuming that each employee makes one access trip per day.

The data in Table 5 show that the ratio of daily employees to enplaned passengers varies widely, from 0.13 to 0.83, with the values for major airline hub airports in the range from 0.3 to 0.6; whereas airports with predominantly origin and destination traffic generally fall in the range from 0.2 to 0.3. The high value for Oakland International is most likely the result of the presence of an on-site major sorting facility for Federal Express, which had relatively low passenger traffic compared with the other airports in the sample. The very low value for San Diego International could be the result of part of the very constrained site, which limits the opportunities for ancillary activities at the airport. The higher values for the major airline hub airports reflect the additional airline activities that occur at those airports, including maintenance activities and crew bases.

The more interesting statistics from the perspective of airport ground access are the ratios of average daily employees to average daily originating passengers. Apart from San Diego International, these range from about 0.25 in the case of predominantly origin and destination airports to a high of 1.55 for Dallas/Fort Worth International. Most of the major airline hub airports have values between 0.7 and 1.0, with Lambert–St. Louis International (which at the time was the main hub for TWA) having a ratio of 1.27. Although person-trips do not translate directly to vehicle trips owing to differing use of high-occupancy vehicles (HOV) and the additional vehicle trips resulting from air passenger drop-off and pick-up trips by private vehicle, this suggests that daily employee vehicle trips at major airline hub airports are of the same order of magnitude as vehicle trips generated by air passengers, and could be significantly higher.

The statistics given in Table 5 also provide a perspective on the relative importance of airport employee trips in the overall pattern of regional travel. A flow of 10,000 to 40,000 trips per day each way clearly has a significant impact on the regional transportation system in the vicinity of the airport, even though it may be only about 1% of the total regional journey-to-work travel (the number of average daily employee trips shown in Table 5 averages approximately 1.1% of the corresponding metropolitan area average weekday journey-to-work trips, although the ratios vary from 0.2% to 2.1% across the different metropolitan areas).

Airport employee travel to and from work differs in a number of ways from typical journey-to-work travel. Major

TABLE 5
AIRPORT EMPLOYEE ACCESS TRIP GENERATION

Airport	Enplaning Passengers 1998	Originating Passengers 1998	Average Daily Employees	Avg. Daily Employees to Avg. Pax per Day	
				Enplaned	Originating
Los Angeles International	30,826,859	18,313,990	40,000	0.47	0.80
Chicago O'Hare International	35,841,551	16,127,120	40,000	0.41	0.91
San Francisco International	19,658,626	12,531,590	31,000	0.58	0.90
Dallas/Fort Worth International	30,121,523	11,279,510	48,000	0.58	1.55
Las Vegas McCarran International	15,132,220	11,114,050	7,500	0.18	0.25
Boston Logan International	13,250,754	10,364,870	14,500	0.40	0.51
Phoenix Sky Harbor International	15,984,620	10,323,330	23,655	0.54	0.84
Seattle–Tacoma International	12,867,830	9,592,000	11,375	0.32	0.43
Denver International	18,444,540	8,956,900	17,400	0.34	0.71
San Diego International	7,453,186	6,980,960	2,600	0.13	0.14
Houston Bush Intercontinental	15,492,252	6,356,870	14,406	0.34	0.83
Tampa International	6,955,805	6,289,530	8,219	0.43	0.48
Lambert–St. Louis International	14,334,844	5,442,800	19,000	0.48	1.27
Portland International	6,487,226	5,353,170	5,000	0.28	0.34
San Jose International	5,202,502	4,861,650	3,500	0.25	0.26
Salt Lake City International	10,097,036	4,762,760	13,026	0.47	1.00
Metropolitan Oakland International	4,612,614	4,183,300	10,500	0.83	0.92
Sacramento International	3,593,647	3,521,200	2,300	0.23	0.24

Source: Leigh Fisher Associates (2000, Table 1-1). Average daily employees estimated for 1998 based on data reported by airport operators. Passenger ratios calculated by author.

Notes: Avg. = average; Pax = passengers.

airports operate 24 hours a day, 7 days a week, and as a result many employees work shifts that are significantly different from the conventional workday. In addition, airline flight and cabin crews often have multi-day duty cycles during which they are away from their crew base. It is unclear how these characteristics cause employee access mode use patterns to be different from more general journey-to-work trips represented in regional travel demand models. Although there may be other trip generators in a region that have similar work shift patterns to those at the airport, these trips are probably not well handled by standard regional travel demand models either.

The survey of MPOs described in chapter three examined how airport employee access travel is handled in regional travel demand models. Although no MPOs reported the use of a special-purpose airport employee mode choice model, six reported the use of a special-generator sub-model for airport employee trips, with the majority treating airport employees the same way as other regional journey-to-work trips. This chapter therefore examines the use of special-generator sub-models for airport travel, as well as a selection of general urban journey-to-work mode choice models, to give an indication of the typical structure of such models.

MODEL APPLICATION

The application of airport employee mode choice models, whether special-purpose models, adapted special-generator sub-models, or general-purpose journey-to-work models, falls into two broad categories. The first is to predict airport employee travel patterns for airport planning studies, whether specifically oriented to employee travel or more general airport ground transportation issues. Airport employee travel accounts for a significant proportion of the vehicle trips generated by airports, particularly large airports, as well as of the ridership on transit services to and from airports. Therefore, modeling these trips forms an important part of feasibility studies for improved airport ground transportation services or infrastructure, as well as studies directed at reducing the environmental impacts of airport activities. In particular, environmental impact documentation for airport projects needs to address airport employee travel as part of considering transportation impacts. Although this can be (and often is) addressed by simply

using existing mode split data from employee surveys or similar sources, to the extent that proposed projects will change the factors affecting employee choices or that proposed mitigation measures have the goal of modifying employee access mode use, it becomes necessary to have tools that can predict the resulting changes in airport employee access mode behavior.

The second category of model application is the representation of airport employee travel in general urban or regional travel modeling. Where airport employee travel is simply treated the same as any other journey-to-work trip then the only question becomes the number of employee trip ends that are assigned to the airport TAZs in the trip generation process. However, where special-purpose airport employee mode choice models or adapted special-generator sub-models for airport employee trips are used, then in addition to the models themselves consideration needs to be given to how the resulting airport employee trip patterns are integrated into the overall trip assignment process.

TECHNICAL APPROACH

In general, the airport ground access modes available to airport employees are the same as those available to air passengers, although some modes, such as rental car and drop off by private vehicle, are not likely to be used by airport employees on a regular basis, whereas other modes that may be available to airport employees, such as car pool and van pool, are not applicable to air passenger travel. This suggests that a similar modeling approach would be appropriate. Given the number of alternative modes that would need to be included in the model, as will be discussed later in this chapter, it would seem likely that a NL model would be the most appropriate structural form (at least at the current state of practice of airport access mode choice modeling). This also corresponds to the current state of best practice for general regional travel mode choice models. Because different factors influence air passenger and airport employee mode choice decisions, the explanatory variables included in the modal utility functions and the market segmentation (if any) used in airport employee mode choice models will be different from that used in models of air passenger mode choice. Pivot-point analysis, as discussed in chapter two, may be an appropriate approach for modeling employee travel where data on existing employee mode use are available.

Airport Employee Access Mode Choice Models

The literature review only identified three studies in which mode choice models were specifically developed to predict airport employee access mode use. All three studies adapted other journey-to-work mode choice models to predict airport employee mode use rather than developing an entirely new model from airport employee travel data.

SERAS Model

A special-purpose airport employee mode choice model was developed for the Greater London region as part of the U.K. SERAS study (Halcrow Group 2002b). This model was a fairly simple binary (two-mode) logit model that predicted the percentage use of private vehicle and public transport. The model used an incremental logit formulation, sometimes described as a pivot-point analysis. Rather than directly predicting the percentage of employees using private vehicles, it predicted the change in the percentage use in terms of the change in the explanatory variables. This change was then applied to the observed mode split in the base case. Mathematically there is no difference between this approach and the use of a regular logit choice model as long as the utility functions in the regular logit model have ASCs to ensure that the mode splits in the base case correspond to the observed data.

The SERAS employee mode choice model was based directly on one developed for the South and West London Transport Conference for a study covering the area to the south and west of London Heathrow Airport. It was therefore felt that this provided a good basis for the SERAS work. However, the Conference study covered all journey-to-work travel, not just airport employees, and thus the model does not include factors specific to airport employee travel (such as irregular shift times or multi-day duty cycles). The parameters used in the SERAS model were derived from an earlier revealed preference study of multi-modal travel, the details of which were not reported. It is unclear whether this earlier study comprised (or even included) airport employee travel.

Because the SERAS model included only two modes, private vehicle and public transport, no account was taken of factors influencing shared-ride behavior. However, the costs and travel times involved in using public transport were obtained from a public transport network model that took into account interchanges between different services (such as mainline rail, London Underground, and local bus). Therefore, the use of different public transport modes is included in the model by implication. The model used a generalized cost approach with separate travel time coefficients for access and egress time, waiting time, and in-vehicle time. In addition, public transport travel times included a constant for travel on each mode, termed a boarding penalty, which reflected relative preferences for different modes. Each bus journey incurred a boarding penalty of 7.5 min, whereas each journey by rail, light rail transit, or guided bus incurred a boarding penalty of 2.5 min. The boarding penalties were added together if a trip involved a change of mode. However, there were no penalties for an interchange within a mode, apart from any waiting time involved. Costs were combined into a single variable. Costs and times were converted to a generalized cost by multiplying travel times by an assumed average value of time. The same value was used for all

employees, because the model was applied at the level of an analysis zone rather than individual employee.

Oakland Airport Connector Model

As part of the analysis for the preparation of an Environmental Impact Report/Environmental Impact Statement for a planned APM connection between the Oakland International Airport and the Coliseum station of the BART system, located approximately 2.5 miles from the airport, an airport access mode choice model was developed and applied to generate ridership projections for the APM connection, termed the Oakland Airport Connector (*BART–Oakland* . . . 2002, Appendix B: Transit Ridership Procedures and Inputs). The mode choice model comprised five market segments covering four air passenger market segments and an airport employee segment.

The airport employee segment of the mode choice model considered only two modes, private vehicle and transit, and used the same coefficient value for both highway and transit travel time, including rail and bus. In addition to travel time, the utility functions included walking distance, waiting time, and cost. The coefficient values were not estimated from employee survey data, but were adapted from the regional travel demand model developed by the MTC, using the mode choice model coefficients for home-based work trips. The ASC for transit does not correspond to the MTC model coefficients and appears to have been estimated to make the transit mode share match observed data for airport employees.

However, the MTC model includes seven modes and several other explanatory variables, including household income and vehicle ownership. It could be expected that excluding these variables from the model would change the appropriate values of the other coefficients, because the behavioral explanation that they provide in the MTC model would now have to be accounted for by the remaining variables. The likely impact of this on the performance of the model is unclear. Furthermore, the MTC mode choice model was estimated using constant 1990 dollars for travel costs. Applying these model coefficients to costs in 1999 dollars, as appears to have been done in the analysis, without making any adjustments for inflation would overstate the effect of cost in mode choice decisions.

A more detailed discussion of this model is provided in Appendix D (web version only) and additional information on the MTC home-based work mode choice model is given later in this chapter.

San José International Airport Model

A very similar approach to that used to model airport employee travel in the Oakland Airport Connector study was followed in a similar model that was developed about a year later for a study of the potential ridership on a planned APM that would connect San José International Airport with a nearby station of the Santa Clara Valley Transportation Authority light rail system (Dowling Associates 2002). As with the Oakland Airport Connector model, coefficients for travel time and cost were adopted from those for home-based work trips in a regional travel demand model, in this case the Santa Clara countywide transportation model, and the ASC for transit was estimated to fit the model predictions of mode use to airport employee survey data. Although details of the Santa Clara countywide model were not reviewed, it appears from the values of the coefficients that the inconsistency in the years in which the cost data was expressed in the two models may be even greater than for the Oakland Airport Connector model.

The application of the model allowed for up to four different connecting transit routes between any given analysis zone and the airport. For those routes involving the use of the APM, the ASC for transit was adjusted on the basis of the results of a stated preference survey performed as part of the study to reflect the greater reported likelihood of using transit if the APM link was available. However, the adjustment was not particularly large and the difference would be offset by a difference in fare of only 20 cents. A more detailed discussion of this model is provided in Appendix D (web version only).

Special-Generator Models

Special-generator models form part of the regional travel demand model and make use of customized techniques to predict travel to zones such as a sports stadium or airport that is not likely to be properly represented by the regular modeling process. Six of the MPOs responding to the survey described in chapter three indicated that they used a special-generator model for airport employee trips, although only one of these, the Houston–Galveston Area Council, provides any relevant information on its website. The Council commissioned a travel survey at Houston Intercontinental Airport in November 1995 to support the development of a special-generator model. This survey assembled data on air passenger ground access travel, airport employee travel, and commercial vehicle trips to and from the airport. In addition to surveys of air passengers, airport employees, and commercial vehicle drivers, traffic counts were undertaken on airport access roadways to develop expansion factors to convert the survey results to daily trips.

The airport employee survey obtained data on household and travel characteristics for 193 employees, including the number of people and workers in the household, the number and age of vehicles available, and the household income. The survey respondents reported an average of 2.4 trips to and from the airport on the travel survey day. The majority were by private vehicle, with 88% auto driver, 10% auto passen-

ger, and 1% each transit and other. These trips were expressed in terms of the trip types used in the regional travel demand model and factored up on the basis of total airport employment to give average weekday trips by trip type.

General Regional Travel Models

The most common way to model employee travel to and from airports is to treat the airport in exactly the same way as any other TAZ in a regional travel demand model and use the trip generation, trip distribution, and mode choice sub-models to generate the number of person and vehicle trips associated with airport employee travel. Typically, an airport will be represented as single TAZ within the regional travel analysis zone system. Most regional travel demand models include separate sub-models for different types of trips, such as travel to and from work or for shopping or recreation. Most models consider journey-to-work, commonly termed home-based work (HBW), trips and assume that the reverse trip is symmetrical (although at a different time of day).

Because the focus of this report is on airport access mode choice, this section provides a brief review of current practice with HBW mode choice models in regional travel demand modeling. However, it should be noted in passing that the total number of employee trips and the resulting travel patterns on the regional transportation network depend on the trip generation and trip distribution components of the regional models as much as on the mode choice component. The extent to which the trip generation relationships incorporated in the regional model are representative of the employment at an airport is an issue that should be considered in interpreting the predictions of airport employee travel produced by a regional model. There are two aspects that may need to be addressed. The first is how well the base year employment levels implicit in the model correspond to actual employment at the airport, whereas the second is how well the model predicts the expected growth in employment at the airport in the future. The first aspect is primarily a question of how well the regional model is calibrated to the airport employment data at the TAZ level. The second aspect relates to how well the way that the regional model predicts future growth in employment corresponds to the expected growth in airport activity and employment. Where there are exogenous forecasts of future airport employment levels, such as forecasts produced by the airport authority, it may be possible to improve the predictions of future airport employee travel produced by the regional travel model by factoring the airport employee trips predicted by the regional model for future years so that the number of employee trip ends in the airport TAZ corresponds to the exogenous forecast of airport employment.

Although trip distribution issues will generally be of lesser concern than trip generation and mode choice, the airport authority will typically have data on the distribution of employee residences that can be compared with the distribution of employee trip origins predicted by the regional model trip distribution process. If the differences are significant, and this is important for a particular application such as predicting the likely demand for a new airport access service, then further adjustments to the employee travel pattern predicted by the regional model may be necessary.

A survey of MPOs recently completed by Vanasse Hangen Brustlin for TRB explored the state of practice in metropolitan area travel forecasting (Vanasse Hangen Brustlin 2007). The survey found that the great majority of the 228 MPOs responding use a trip-based four-step or similar travel forecasting process. However, although approximately 95% of the large MPOs reported that they used a mode choice model for HBW trips, overall slightly less than 50% of the MPOs modeled HBW mode choice. About three-quarters of the large MPOs use a NL models for HBW trips. The study presented data on the frequency of use of different modes in the mode choice models, but did not indicate which of these were used for HBW trips or provide any information on the explanatory variables used or how the modes were nested.

Home-Based Work Mode Choice

To illustrate the variety of model structures and explanatory variables included in typical HBW mode choice models, this section presents some technical details on five representative models for the following regions: Atlanta, Dallas/Fort Worth, the San Francisco Bay Area, Seattle, and Metropolitan Washington (the Baltimore–Washington region). Each of these models differed in a number of ways, including the modes represented, the structural form of the model, and the explanatory variables. Because of the complexity of the models, their need to reflect the different transportation facilities and geographical aspects of each region, and differences in the underlying transportation system data used to apply the models, this discussion does not cover all the details of the models, for which the interested reader is referred to the technical documentation referenced in the discussion, but rather attempts to provide a comparative overview to give a broad sense of how these models function and differ.

The principal characteristics of the five models are summarized in Table 6, which shows the model structure, the modes included in the model, and the explanatory variables used in each of the models. Four of the models were true NL models with two or more levels, whereas the fifth consisted of two linked MNL models that were estimated sequentially. The terminology varied in the documentation for the different models (e.g., some models refer to shared-ride auto trips, whereas others use the term group ride), but consistent terminology has been used in the following discussion for clarity. Therefore, the terminology in the discussion of a specific model may differ slightly from that used in the model documentation.

TABLE 6
CHARACTERISTICS OF SELECTED HOME-BASED WORK MODE CHOICE MODELS

	Regional Model				
	ARC	MTC	MWCOG	NCTCOG	PSRC
Model Structure					
Sequential multinomial logit			✱		
Nested logit	✱	✱		✱	✱
Modes Included					
Drive alone	✱	✱	✱	✱	✱
Shared ride 2	✱	✱	✱	✱	✱
Shared ride 3	✱		✱		
Shared ride 3+		✱		✱	✱
Shared ride 4+	✱		✱		
Transit auto access	✱	✱	✱	✱	✱
Transit walk access		✱	✱	✱	✱
Bus transit walk access	✱				
Rail transit walk access	✱				
Bicycle		✱			✱
Walk		✱			✱
Nests					
Motorized (auto, transit)		✱			
Drive alone/shared ride	✱			✱	
Drive alone/drive to transit					✱
Shared ride			◆[a]		
Transit access	✱	✱			
Bus vs. rail transit	✱				
Variables					
In-vehicle travel time	✱	✱	✱	✱	✱
Waiting time	◆[b]	✱	✱	✱	✱
Walking time	◆[b]	✱	✱	✱	✱
Bicycle time					✱
Trip cost	◆[b]	✱	✱	✱	✱
Persons/household		✱		✱	
Workers/household		✱			
Vehicles/household		✱	✱		
Vehicles/worker					✱
Households w/ vehicles < people				✱	
Bus miles in peak hour	✱				
Household income	✱	✱		✱	
Employment density		✱			
Land use mix index			✱		
Sub-area dummy variables	✱	✱		✱	✱

Model: ARC = Atlanta Regional Commission (*Travel Demand . . .* 2005).
MTC = Metropolitan Transportation Commission (Purvis 1997).
MWCOG = Metropolitan Washington Council of Governments (*COG/TPB Travel . . .* 2007).
NCTCOG = North Central Texas Council of Governments (*Dallas–Fort Worth Regional Travel Model . . .* 2007).
PSRC = Puget Sound Regional Council (Cambridge Systematics 2003).

[a] Estimated as separate multinomial logit model.
[b] Coefficients adopted from other models.

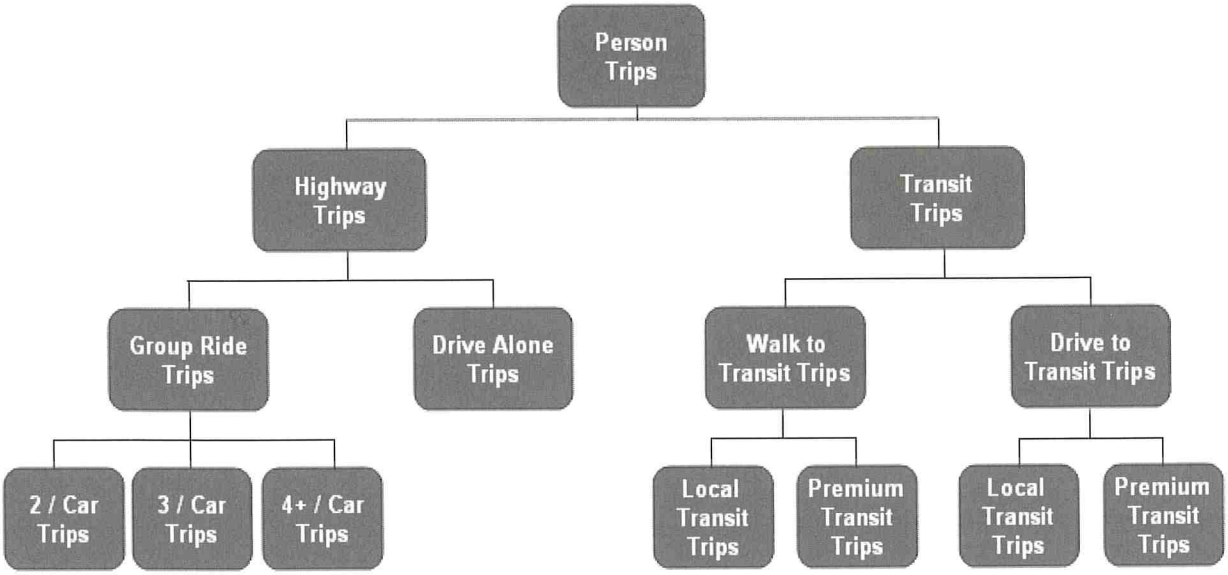

FIGURE 6 Home-based work mode choice structure—Atlanta region. (*Source: Travel Demand . . .* 2005).

All five models distinguish between single-occupant auto trips (drive alone) and at least two categories of shared-ride auto trips. Three models have three vehicle occupancy categories (drive alone, two people, and three or more people), whereas two of the models add a fourth category and distinguish between three people and four or more. The representation of transit in the models is more varied. All the models distinguish between walk access and automobile access to transit in some way; however, the details differ. Some models represent the access mode as a secondary choice, whereas others treat walk access to transit and auto access to transit as separate modes. The Metropolitan Washington model (*FY-2003 Models . . .* 2007) assumes either walk access or automobile access to transit based on the distance from the trip origin to the nearest bus stop or rail station. Transit trips beyond the assumed maximum walking distance from the nearest rail station but within walking distance of a bus stop are assumed to walk to the bus stop. Use of rail or bus then depends on the quickest path through the transit network. Two of the models included bicycle and walk the entire trip as alternatives in the choice set for some trips.

Not only did the models differ in which modes they included but the way in which the modes were nested differed across every model. The Atlanta HBW regional model (*Travel Demand . . .* 2005) divides person-trips into highway trips and transit trips at the top level and then at the second level splits highway trips into drive alone and shared-ride and transit trips into walk access and automobile access. Shared-ride auto trips are split into three vehicle occupancy categories at the third level, whereas walk access transit trips are split into local bus and rail rapid transit service (termed premium transit) trips, as shown in Figure 6. This structure implicitly assumes that the disutility involved in choosing to walk to transit depends on a lower-level choice of whether to walk to a local bus stop or walk directly to a rail station. Although some travelers indeed face this choice, most do not and have a trip end far enough from the nearest rail station that their options are to drive to the station or walk to a local bus stop. Those who choose to walk to a local bus stop may subsequently use the rail rapid transit system depending on their route through the transit network.

In contrast, the HBW mode choice model for the Seattle region (Cambridge Systematics 2003) has five modes and one composite alternative at the top level: auto, two-person shared-ride, three or more person shared-ride, walk access to transit, walk to destination, and bicycle, as shown in Figure 7. The auto composite alternative is split into drive alone and auto access to transit at the second level. This structure implicitly assumes that the disutility involved in choosing to make an auto trip depends on a lower-level choice of whether to drive alone to the destination or to an intermediate transit stop or station. In the case of automobile access to transit, the perceived disutility of the alternative will include the effect of the travel time and cost involved in riding transit.

The HBW mode choice model for the San Francisco Bay Area (Purvis 1997) lies somewhere between the Atlanta and Seattle models, as shown in Figure 8. At the top level there is a choice between motorized modes (both automobile and transit), bicycle, and walking to the destination. The motorized modes are then split into three auto modes (drive alone,

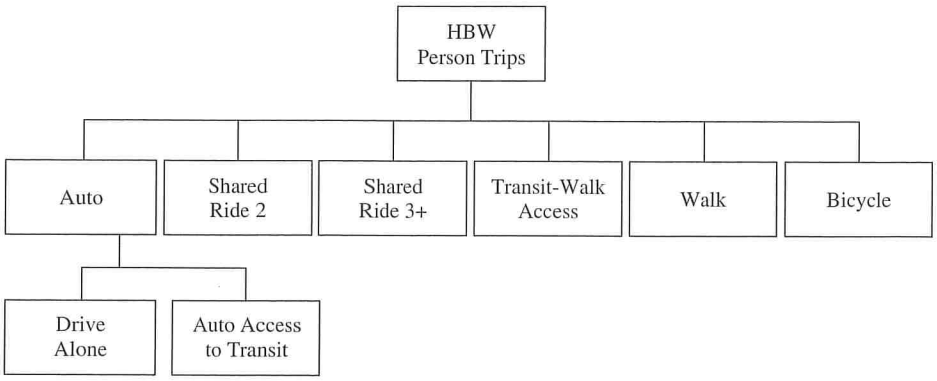

FIGURE 7 Home-based work mode choice structure—Seattle region. (*Source:* Cambridge Systematics 2003.)

two-person shared-ride, and three or more person shared-ride) and transit. At the third level, transit trips are split into automobile access and walk access. There is no explicit distinction between the use of local bus or regional rail services (BART or commuter rail); however, the use of rail depends on the path taken through the transit network.

The HBW models for the Dallas/Fort Worth region (Cambridge Systematics n.d.; *Dallas–Fort Worth* . . . 2007) and for the Metropolitan Washington region (*COG/TPB* . . . 2007) both have a somewhat simpler structure than the other three models, with only three alternatives at the top level, one of which is split into three modes at the second level. However, the modes at each level are different. The NCTCOG model has an auto composite alternative at the top level, together with walk access to transit and auto access to transit as separate modes. The auto composite alternative is then split into three modes at the second level: drive alone, two-person shared-ride, and three or more person shared-ride. The Metropolitan Washington Council of Governments (MWCOG) model has the following three alternatives at the top level: transit, drive alone, and shared-ride auto (termed group ride). As described previously, access to transit is not explicitly modeled as a mode choice, but transit trips are assumed to involve either walk access or automobile access depending on the distance to the nearest bus stop or station. The shared-ride alternative is then split into three carpool/vanpool modes at the second level for different vehicle occupancy: two-person shared-ride, three-person shared ride, and four or more person shared-ride. The split into three carpool/vanpool modes is done with a separate carpool occupancy model that is estimated independently from the top-level model. The resulting vehicle occupancy information is then used in the main model to determine the average costs for the shared-ride mode for each person.

Variables Used in Models

The range of explanatory variables included in the utility functions of the HBW models varies from region to region, as indicated by Table 6. Furthermore, not all variables used in a given model are used in the utility function for each mode because many of the variables, such as waiting time or bicycle travel time, are only relevant for some modes. Other variables that are not mode-specific, such as measures of vehicle ownership, have been found to provide a statistically significant contribution to the explanatory power of the model when included in the utility function for some modes but not others.

All five models include measures of in-vehicle travel time, waiting time, walking time (or walking distance), and travel cost, although the coefficients for travel time and cost in the Atlanta model were adopted from other regional models rather than being estimated from local data. Some models used the same travel time or travel cost coefficients for each mode, whereas others estimated different coefficient values

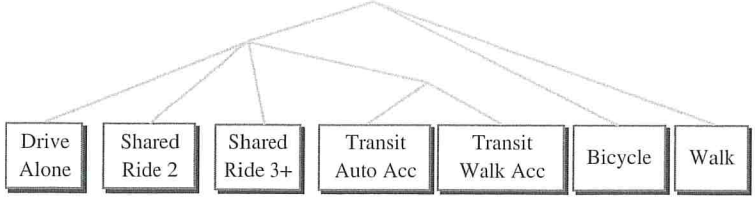

FIGURE 8 Home-based work mode choice structure—San Francisco Bay area. (*Source:* Purvis 1997.)

for different modes, typically distinguishing between transit and automobile use. Similarly, some models estimated separate model coefficients for different travel time components, such as waiting or walking, whereas others assumed that these coefficients were a fixed multiple of the in-vehicle travel time coefficient and only estimated a single coefficient for the weighted travel time. If the assumed weighting factor for the out-of-vehicle time components is incorrect, this will bias the estimated values of the coefficients for each of the travel time components.

Only three of the regional models included household income in the model in some form, and the approach varied across the models. The Bay Area model used a continuous variable for household income up to a maximum value of $25,000 in 1989 dollars. The NCTCOG model used dummy variables for low- and high-income households, defined as those with incomes of less than $30,000 or more than $75,000 in 1996 (when the household travel survey used to estimate the model was performed). Separate values of the dummy variable coefficients were estimated for each mode. The Atlanta model stratified the model estimation sample into four household income groups, with household incomes in 2000 dollars of less than $20,000, $20,000 to $49,999, $50,000 to $99,999, or $100,000 or more. Separate ASCs were estimated for each income group for each mode apart from local bus and rail rapid transit. Estimating separate ASCs is effectively the same as using a dummy variable for those income groups.

Two of the models considered employment density in the destination zone, whereas a third model used an index of land-use mix in both the origin and destination zone to explain differences in mode use behavior in different areas of the region. Four of the models used dummy variables for certain sub-areas within the region, although the way that these were defined and how extensively they were applied varied widely. The use of sub-area dummy variables provides a way to adjust the model predictions to better match observed mode shares in specific areas. Although this improves the fit of the model to the estimation data, it also implies that the other variables in the model are not adequately explaining the observed choice behavior for those areas. This could in turn lead to forecasting errors when the model is used to predict travel patterns in future years when the conditions or influences reflected by the other variables are expected to change.

Because of the differences in the way that the variables are defined in each model and of the differences in functional form, the specific values of the coefficients are not directly comparable. Similarly, differences in the years when the data were collected from which the models were estimated, as well as differences in the way that household income was (or was not) included in the models, means that implied values of travel time are also not directly comparable. The work required to reexpress this information on a consistent basis is beyond the scope of the current study.

Summary

Although the current state of practice of regional travel demand modeling is fairly consistent in broad terms among large metropolitan planning agencies, the details of how the components of this process are implemented vary widely from region to region. Therefore, the use of these models to study airport employee mode choice in a specific region should be approached with caution. There is a need for significantly more work to determine how the differences in the models could affect their ability to predict journey-to-work travel behavior of specific sub-groups of the larger regional population, such as airport employees.

MODES INCLUDED IN MODEL

Generally, the modes included in airport employee mode choice models are more limited than those for air passenger mode choice models, because many of the modes used by air passengers are not relevant to airport employee journey-to-work trips. Airport employees will not usually consider renting a car to get to work (except perhaps in the rare case where their own car is not available), whereas modes such as taxi and limousine are too expensive for use on a regular basis. Although modes such as scheduled airport bus or shared-ride door-to-door van will often be too expensive to be a viable option, the cost of using these modes may be affordable if discounted fares are available to airport employees.

On the other hand, airport employees may have access services available to them that are not available to air passengers, such as dedicated employee buses or van pools. Unlike air passengers, who generally cannot arrange to share a ride to the airport with another air party other than by the use of commercial shared-ride services, airports or airport employers often establish ride-matching services to arrange car or van pools, or airport employees may be able to make use of local ride-sharing organizations.

Given the interest of many regional transportation planning agencies in modeling shared-ride trips, as well as that in many regions the number of vehicle occupants affects the ability to use HOV lanes or avoid paying tolls, it is desirable that airport employee mode choice models identify the number of occupants in car or van pools. This is necessary anyway to be able to convert from employee trips to vehicle trips. However, where the number of occupants that are required to use HOV lanes varies for different facilities in the region, then determining an average vehicle occupancy for shared-ride trips is not sufficient and it will be necessary to distinguish between the occupancy categories that allow the

use of each facility (typically shared-ride occupancy criteria are either two or more people or three or more). Although there may be no reason to distinguish between formal van pools and car pools with three or more people from the perspective of HOV lane use, it may be desirable for other reasons, such as evaluating the effectiveness of ride-sharing programs or because van pool vehicles are provided by the airport or employer.

Although airports are typically located sufficiently far from residential areas that walking is not usually a feasible access mode for the entire journey to work (as distinct from the access or egress trip from other modes), some employees may cycle to work, particularly if the airport provides facilities to encourage this. Indeed, the provision of such facilities may form part of airport ground access trip reduction or mitigation programs. Therefore, a fairly comprehensive airport employee mode choice model might include the following modes:

- Single-occupant private vehicle
- Shared-ride private vehicle—two occupants
- Shared-ride private vehicle—three or more occupants
- Van pool
- Charter bus or van
- Public transit
- Scheduled airport bus service
- Bicycle.

Depending on the application, it may also be desirable (or even necessary to estimate the model coefficients adequately) to include sub-modes such as different parking locations, different transit services, and different access or egress modes to or from the stations or stops used for public transit or other fixed-route services, as with air passenger mode choice models. Although mode choice models developed for general urban travel are increasingly incorporating a wider range of modes and many explicitly considering how transit users will access transit services, very few current models include the range of modes that are typically available to employees at a large airport. Even so, as a wider range of modes is included in the more sophisticated regional travel demand models, including different types of shared-ride trip and nonmotorized modes such as cycling, these may have an adequate degree of resolution to model airport employee trips.

As the number of different modes and sub-modes included in the model increases, so the structure of the model becomes an important issue. The MNL model is predicated on the assumption that the utility of each mode is independent of that of other modes, which is clearly not the case with many of the modes discussed earlier. This difficulty can be overcome with the use of a NL model. However, this raises the question of how best to group the modes into different nests. This is an issue that deserves further research, as evidenced by the widely different model structures used in different regional travel demand models, which is discussed later in this chapter.

Because of the timing of shift start and end times, airport employee travel may well occur at times when some modes, particularly public transportation services, are not available. This will need to be reflected in the mode choice model through constraints on mode availability. Shift times will also constrain the ability of employees to find a car or van pool at the appropriate time, and this needs to be reflected in how these modes are represented in the model.

EXPLANATORY VARIABLES

As with air passenger airport access mode choice models, airport employee mode choice models will need to include travel time and cost variables. Although costs can be aggregated into a single variable, the different components of travel time (walking, waiting, and in-vehicle time) should be expressed as separate variables to allow for the possibility of different perceived disutility of each component.

An important consideration in determining the values of explanatory variables is how to represent travel constraints arising from the timing of shifts. Where highway travel times or transit travel times, service frequency, or fares vary significantly by time of day, it will be necessary to ensure that the appropriate values are used for each employee. It may be desirable to have separate travel time variables for use of public transportation late at night to reflect differences in perceived disutility owing to concerns for personal security, in addition to greater travel time as a result of infrequent service. However, the majority of regional travel demand models provide limited resolution for differences in travel times by time of day. It is not uncommon to only model the morning commute peak and average off-peak conditions, which will not distinguish between mid-day and late night conditions. In this situation, it will not be possible to obtain the appropriate travel times directly from the regional travel demand model data files and significant adjustments may be needed to appropriately represent late night travel times on public transportation.

Where employees pay for parking (or a transit pass) through a payroll deduction, it may be desirable to use a separate variable for this cost component to allow for the possibility that employees may perceive this cost differently from a regular out-of-pocket expense. In the case of a transit pass, there is also the benefit that the pass can usually be used for other transit trips in addition to the journey to work.

Employee income level is likely to be a significant factor in mode choice and an appropriate variable should be included in

the model. Employee wage rate is likely to be a more relevant measure than household income, because the latter may be unduly influenced by the income of other workers in the household.

MODELING CONSIDERATIONS

Development of airport employee access mode choice models requires both survey data on existing employee mode use patterns and service data on the costs and travel times involved in using the alternative modes available. Much of the modal service data, such as highway travel times and transit travel times and frequencies, are the same as that required for developing air passenger airport access mode choice models. However, additional data will have to be collected on employee-specific costs, such as parking fees, transit passes, and employee discounts on scheduled airport bus services, as well as information on employer-provided services such as free parking or employee charter buses.

As with air passenger airport access mode choice, the range of factors that influence the mode choice decisions of a given employee are sufficiently individual-specific that any reasonable model will have to be disaggregate in nature and predict the probability of a given employee choosing a particular mode. This implies that such a model can only be developed from fairly detailed survey data of a large enough sample of employees. In addition to information on the existing mode use, the survey needs to collect data on all the factors that might reasonably influence that choice, including the respondent's shift patterns, type of work, residence location, wage or salary level, and eligibility for any special benefits, such as free parking or transit passes, even if the respondent is not actually using that benefit.

It will also be necessary to determine the respondent's employer (or at least the type of employer), because this is important in expanding the model to predict airport access mode use patterns for all airport employees, not just the respondents to the survey. Because the survey response rate is likely to vary across employers or even departments within an organization, reflecting different managerial support for performing the survey or even willingness to participate, it will be necessary to develop expansion factors for each respondent based on the total employment within each organization or unit. Fortunately, the requirement for most airport employees to have security badges means that the airport authority usually has good data on the number of employees in each category.

Given the very limited experience developing employee access mode choice models, it is unclear how large a sample size would be necessary to estimate a reasonably accurate model. This is yet another aspect that would benefit from further research. Until this issue is better understood, based on experience with air passenger access mode choice models, an airport undertaking an employee survey for use in developing such a model should attempt to obtain as large a sample as possible, in the range of 1,000 to 3,000 responses.

Although not strictly an airport employee mode choice modeling issue, the application of an airport employee mode choice model requires an airport employee trip generation model that predicts the number of airport employees living in each TAZ and generates a representative sample of airport employee trips with their associated characteristics. Unless the employee survey responses are a very large sample of total employment, simply factoring up the employee characteristics from the survey by the ratio of the total airport employment to the survey responses will result in a trip generation pattern that has a large number of employees with identical characteristics from some TAZs and no employee trips from other zones. This will tend to overstate the potential for ridesharing, as well as bias the predicted mode use from any given zone.

This issue is not that different from regional travel demand models, which typically include a trip generation model component. However, the journey-to-work trip generation models in regional travel demand models cover all types of employment and typically do not generate individual traveler characteristics, much less those appropriate to airport employees (such as shift start and end times). Therefore, it may be desirable to generate a synthetic sample of trips using Monte Carlo simulation methods based on the distribution of airport employee characteristics obtained from an employee travel survey.

It is common practice in regional travel demand modeling to treat the airport as a single TAZ. This is reasonable within the context of the overall regional travel demand, but may not be adequate for airport planning studies, particularly where different areas of the airport may be served by different access roads. Therefore, it may be desirable to subdivide the airport into different zones and identify the level of airport employment in each zone as well as use a more refined representation of the transportation network in the vicinity of the airport. Although this will not significantly change travel times to trip origin TAZs at some distance from the airport, it may affect travel times for those employees who live closer to the airport and will be necessary to properly assign to trips to the different access routes.

MODEL PERFORMANCE

Given the limited experience with special-purpose airport employee mode choice models, there is no basis for assessing the likely performance of such models. Assessments of the overall performance of general regional travel models shed little light on their performance at predicting airport employee mode choice, because airport employees form such a small percentage of the total regional journey-to-work

travel. It would of course be possible to compare the regional travel model predictions of journey-to-work mode use for the airport TAZs with data from airport employee surveys. However, no such studies have been identified. This would appear to be a promising area for further research, because it is fairly simple to do and would provide valuable information on the extent to which existing regional travel models can be used to predict airport employee mode use.

As with air passenger airport access mode choice models, assessment of the performance of existing models is critical to understanding how much reliance can be placed on their predictions and identifying the need for further improvement in these models. However, before the performance of special-purpose airport employee mode choice models can be assessed, it is first necessary to develop the models to assess. This is another area that could benefit from further research.

CHAPTER SEVEN

TRANSFERABILITY OF AIRPORT GROUND ACCESS MODE CHOICE MODELS

Given the considerable cost and effort required to develop models of airport ground access mode choice, it is natural to ask whether separate models need to be developed for every airport or whether it would be possible to adapt or apply a model developed for one airport at another. This would depend on how transferable such models are. In general, experience applying models of transportation behavior in situations that are different from the one for which they were developed has been mixed. An early study of the transferability of work-trip mode choice models (Atherton and Ben-Akiva 1976) suggested that these models might transfer fairly well. However, further work that examined model transferability issues in more detail (McFadden et al. 1977) found that whereas the evidence for transferability of work-trip mode choice model coefficients between different market segments within a region was mixed, their transferability between regions did not appear very encouraging. Subsequent work (Pas and Koppelman 1984; Badoe and Miller 1995) showed that although mode choice models appeared reasonably transferable within the same metropolitan region, the model parameters were not temporally stable. McCoomb (1986) estimated journey-to-work models for the ten largest Canadian cities using the same mode choice model specification and consistent travel data that was collected for each city using the same survey for the same day. Although the model coefficients were found to differ across the cities, some models were similar enough to lead the author to conclude that they could be transferred when the cities are reasonably similar in size, urban structure, and transportation system. The importance of consistent data as a requirement for model transferability has also been noted by Galbraith and Hensher (1982).

More recently, Rossi and Outwater (1999) undertook a comparative analysis of mode choice model parameters for home-based work, home-based non-work, and non-home-based segments of regional travel demand models for 11 U.S. metropolitan areas. The values of the parameters for a given variable were found to vary quite widely, particularly for home-based non-work and non-home-based trips. The authors undertook a simple experiment of applying the parameters for each of the regional models to a hypothetical origin-destination zone pair in some other region after obtaining ASCs for transit for the other region by fitting each model to an assumed transit share in a different origin-destination zone pair. The results showed that the estimated transit share in the test market varied from 10.2% to 19.8%, or by a factor of almost two. The authors concluded that whereas transferring mode choice model parameters may sometimes be necessary where adequate data are not available to estimate a model on local conditions, the results should be used with caution. They also stress that the complete model should always be used and not just selected coefficients, because variables may be correlated with each other.

For readers interested in more details on past work on model transferability, there is a good summary of the literature on the transferability of regional travel demand models by Karasmaa (2003).

Past studies of travel demand model transferability have focused on models of general urban travel behavior, which includes a wide range of trip purposes that are likely to be heavily influenced by the local characteristics of the transportation system, and airport ground access travel behavior may be more consistent. In principle, one would expect that air travelers would behave similarly when faced with a similar choice situation, controlling for differences in ground access service characteristics (e.g., fares or travel times) and differences in traveler characteristics (e.g., trip purpose and duration, household composition, and income). Airport access mode choice models attempt to account for the effect of these variables on the choices made by a given air party. Therefore, to the extent that a model accurately reflects the effect of these variables, it should explain the behavior of air parties in other geographic regions. However, this is a significant caveat that may well not hold for reasons discussed here.

In particular, there may be regional differences in attitudes toward the service characteristics of different modes, as well as differences in the nature of the services offered. This is likely to be a significant consideration with the use of public transit services. Air travelers living in large metropolitan areas with well-developed transit systems are more likely to consider using public transportation for a trip to the airport than those from areas with less extensive transit services and less use of transit, partly owing to familiarity and comfort with using public transportation and partly the result of differences in automobile availability. Whereas differences in service characteristics of different modes should in principle be accounted for by the explanatory variables in the model, in practice this is not necessarily the case. Misspecification of utility functions or inaccuracies in the values of service characteristics used for model estimation can result in biased values of the ASCs or coefficients of other variables that will result in biased estimates of the utilities of each mode when these coefficients are applied in different situations.

ISSUES IN MODEL TRANSFERABILITY

Because the mix of air passenger or airport employee characteristics and the details of the airport ground transportation services that are available differ widely from airport to airport, for an airport access mode choice model to be transferable it must correctly reflect the influence of the different factors that determine airport traveler ground access mode choice. If model coefficients are partly accounting for factors that are not directly associated with the variable in question (or are inherent to the mode in the case of the ASCs), then differences in these factors when the model is applied in other situations will result in biased estimates of the modal utilities and errors in the predicted probabilities of using each mode.

Although this applies to the transferability of a model from one region to another, it also applies when a model is used to analyze a significant change in the ground transportation system serving the airport for which it was developed, such as the addition of a new mode or service, as well as the application of a model to forecast future mode use, as discussed by Gosling (2006). Therefore, ensuring that models correctly reflect the factors that influence mode choice decisions not only improves their transferability to other regions, but also their use in planning studies at the airport or airports for which they were developed. This is a lot easier said than done.

In particular, model transferability is likely to be influenced by the following factors:

- Incorrect or incomplete model specification,
- Missing explanatory variables,
- Incorrect market segmentation, and
- Problems with the data used to estimate the model coefficients.

VARIABILITY IN MODEL SPECIFICATION

Although there are a fairly limited number of different airport access mode choice models that have been documented in the review of recent literature and professional practice, it is relevant to ask how consistent these models are in terms of their functional specification and use of explanatory variables. Wide variation in model specification would suggest that either the underlying behavior that they are attempting to explain varies widely from region to region or the models do not correctly reflect that behavior in their technical specification. Either way, this would suggest that they are not likely to be reliably transferable to other situations.

Functional Form

Although a number of recent models have continued to use a MNL structure, the more advanced models have used a NL structure. There are sound theoretical reasons why the NL structure should be superior to the MNL, particularly if the model attempts to include modes that are likely to be perceived as having a stronger substitutability with some alternative modes than others or to distinguish between different secondary modes that are used to access a primary mode, such as parking at an off-airport terminal compared with being dropped off by private vehicle.

Because the nesting structure of the limited number of models that have used a NL structure is very dependent on the particular modes that exist in the region being modeled, it is difficult to generalize about how the various models have grouped the modes. The model for Boston Logan International Airport developed by the Central Transportation Planning Staff (Harrington et al. 1996; Harrington 2003) adopted a hybrid structure, in which the resident models were nested but the nonresident models were not. The resident models included an automobile nest (drop off, short-term parking, and long-term parking on and off airport) and a door-to-door nest (taxi and limousine). The public transport modes (MBTA transit, scheduled bus/limousine, Logan Express, and Water Shuttle) were not nested, although that would have been redundant because there were no other modes at the top level of the tree. In contrast, the nesting structure of the SERAS Air Passenger Surface Access Model (Halcrow Group 2002b) involves up to six levels of nest, including a three-level nest of different rail options. The decision of which modes are nested together appears to have been made on the basis of what gave the model the best fit. For some market segments the use of taxi and drop off by private vehicle (termed kiss and fly) are grouped in the same second-level nest, with private vehicle parked for the trip duration (termed park and fly) at the top level, whereas for other market segments all three modes are at the top level or are grouped differently at lower levels.

However, the discussion of household income brings up an interesting issue with respect to model transferability, namely how to reflect differences in the cost of living in different regions. Although including household income in an airport access mode choice model in some way is clearly necessary if the model is to correctly reflect traveler behavior, a given income level may provide more disposable income in one region than in another. The extent to which this will influence traveler sensitivity to time and cost tradeoffs in airport access trips is unclear.

Explanatory Variables

Differences in the explanatory variables included in different airport access mode choice models, although not necessarily a problem for model transferability, do raise questions about the extent to which the model coefficients may be explaining factors not directly measured by the variables in question. The absence of studies that have taken a model estimated in

one region and applied in another to compare the model predictions with the observed mode choices in the second region makes it difficult to assess how sensitive the model predictions might be in such a situation to the choice of variables included in the model. In particular, the absence of a household income variable (or equivalent measure of the perceived value of time) in many models means that such models would most likely not work well at all if applied in a situation where the distribution of household income is very different.

An ideal model would not have ASCs in the utility function because these imply that the mode will have some probability of being selected even if the values of all the continuous variables are zero. Rather, the intrinsic attributes of the mode would be expressed through appropriate continuous variables that could be adjusted for different situations. However, in practice the ASCs account for missing variables and other data problems and frequently take values that are quite large compared with the effect of the continuous variables. This is likely to be a significant problem for the transferability of these models, because the factors represented (at least in part) by the values of the ASCs are not likely to occur in the same way in another situation.

Market Segmentation

This is the aspect in which there is the most consistency in recent airport access mode choice models. It has become general practice to develop separate sub-models for four market segments (although terminology may vary slightly) comprising:

- Resident business trips,
- Resident non-business trips,
- Non-resident business trips, and
- Non-resident non-business trips.

This market segmentation recognizes that residents of the area have different airport access mode options than visitors to the region (non-residents) and that travelers on business trips may value their time differently from those on personal trips. There is also the consideration that many business travelers are able to charge their travel expenses to their employer or client. The need of some visitors to rent a car for their local travel while in the area is another important difference between residents and visitors. Once a decision is made to rent a car for other reasons, then that typically predetermines the airport access mode choice.

However, examination of recent airport access mode choice models suggests that this four-way market segmentation may be too simplistic to fully reflect the factors that shape airport access mode choice behavior. Visitors staying with friends or relatives often have access to a private vehicle for local travel (indeed, the local travel may be undertaken together with those they are visiting) as well as people who can pick them up from the airport and drop them off, whereas those staying in a hotel or visiting a business typically do not. Similarly, travelers on business who can charge their travel expenses to an employer or client may behave very differently from those who have to meet their travel expenses out of their own pocket or out of a limited travel budget. Thus, there may be significantly different behavior by someone traveling to a professional conference at their own (or their organization's) expense compared with someone attending a meeting the costs of which they can charge to a client. Although these issues have typically been handled (if at all) through the specification of the utility functions, this imposes limitations on the ability of the model to reflect the relevant behavior and it may be better to address these issues through more detailed market segmentation.

COMPARATIVE ANALYSIS OF MODEL PARAMETERS

Although the numerical value of the model coefficients in a nested or MNL model have no direct significance because they depend in part on the variance in the dataset from which they have been estimated, the ratio of two coefficients does have an interpretable meaning that can be compared across different models. The ratio of the travel time coefficient to the cost coefficient represents the implied value of travel time. Similarly, the ratio of coefficients of other variables to the travel time coefficient can be interpreted as a factor that converts the values of the other variable to equivalent minutes of travel time.

Even if the implied value of travel and other continuous variables is reasonably consistent between two models, the values of the ASCs are likely to be problematic from the perspective of the transferability of a given model. If indeed these coefficients represent intrinsic characteristics of the mode that will be similar in other situations, then using them in another situation should produce reasonable results. However, in practice they are likely to account for missing variables, model specification errors, inaccuracies in the estimation dataset, and other issues. To the extent that these are likely to be different in different situations, the use of the ASCs in the second situation would most likely generate incorrect results.

DATA CONSIDERATIONS

It is a truism that a model is only as good as the data from which it was developed and with which it is applied. This is particularly relevant to airport access mode choice models owing to the extensive amount of data that are needed to develop and apply them and because much of these data are not readily available. Errors in the data used for model estimation will result in biased model coefficients, as those coefficients attempt to explain behavior in terms of data that are incorrect. Errors in the estimation data will not typically be detected by the usual tests of model goodness-of-fit. Similarly, even if the

model is estimated on valid data and the model coefficients are not biased by data problems, applying the model with incorrect data will produce incorrect results.

Potential data problems arise in both of the two broad categories of data required for their development: survey data of air passenger or airport employee characteristics and data on the transportation service levels in the airport ground access system.

Air passenger and airport employee surveys are rarely truly random samples of the underlying population, although this is often overlooked in their analysis. In particular, the logistics of performing air passenger surveys necessarily restricts the sample to a subset of the total population. Surveys are typically performed for a limited time period and often for only part of each day on which the survey takes place, owing to staffing considerations. Air passenger surveys are often done in airline gate lounges, because that is a location in which passengers are most likely to be willing to take the time to answer a survey. However, this limits the sample to passengers on specific flights traveling to a specific destination. Although an effort is typically made to survey a reasonably representative sample of flights, budget limitations on the number of flights that can be surveyed will usually result in a biased sample. This can be partly corrected by appropriate weighting techniques; however, careful thought needs to be given to how this is done. Weighting responses to correct for one issue such as the distribution of responses by flight destination can exacerbate any bias in the responses with respect to a different issue, such as the distribution of responses by time of day.

The second set of problems that can arise with air passenger and airport employee surveys relates to question wording or which questions are asked. Omitting a topic in the survey, such as the household income of the respondents, necessarily precludes including that factor in the specification of a mode choice model estimated from the data. Poorly worded questions can also introduce errors in the data. Air passengers in particular may not use the same terms to describe their trip characteristics or ground access modes used as the designers of the survey expected. For example, an air passenger may refer to a shared-ride van as a limousine (indeed some shared-ride van operators use the word limousine in the name of the service). Although these errors in individual responses may not be too serious in presenting the aggregate results of the survey, particularly where there may be offsetting errors by other respondents that reduce the overall error in the results, they can have a significant impact on the use of survey results to estimate disaggregate mode choice models that attempt to explain why individual survey respondents chose the access mode that they did.

Whereas in principle it should be fairly easy to determine the travel times and costs of using different access modes from existing data sources, such as the regional transportation planning process or airport ground transportation information systems, in practice this is often problematic and prone to error. Highway travel times vary by time of day and day of the week. Although regional transportation planning agencies are increasingly developing datasets that better reflect this variation, it is still common for planning agencies to divide the day into a limited number of time periods (e.g., the a.m. peak period, p.m. peak period, and off-peak period) and determine average weekday travel times for each period. However, airport travelers will base their ground access decisions on how long they think their trip will take at a particular time of day, which may be quite different from the travel times given by the regional transportation network datasets. Airports, particularly large airports, are typically served by a large number of private transportation providers, such as shared-ride van or limousine (black car) services, that may charge a wide range of fares that vary by the location of the trip origin as well as from provider to provider. The travel time involved in taking a shared-ride van is also influenced by how many other travel parties have to be picked up or dropped off. Basing the mode choice model estimation on travel time and cost assumptions for each mode that is different from what the travelers perceived those values to be when they made their decision will inevitably bias the model.

SUMMARY

Given the current lack of consensus over model specification and typical coefficient values between different airport access mode choice models, it can be assumed that the transferability of these models is highly suspect. Although it seems plausible that the underlying airport traveler behavior may not differ that much from region to region, after taking into account differences in air passenger or airport employee characteristics and transportation system service levels, it appears unlikely that current airport access mode choice models do this correctly, based on the significant differences between the different models.

Both because of the obvious value of being able to apply airport access mode choice models in different situations from those for which they were originally developed, as well as the concerns about the reliability of even applying them to different situations at the airports for which they were developed, there is a pressing need to better understand how well current models reflect the factors influencing the underlying travel behavior and how they can be improved to better reflect this behavior. It is not sufficient to simply say that existing models are unlikely to be transferable and that a new model must be developed for every application. This is to admit that the existing models do not properly reflect the causal structure of the underlying traveler behavior and by implication calls into question the reliability of the predictions generated by these models.

In the event that a study sponsor does not have the resources or time to develop a new mode choice model for a

particular planning study where an existing model is not available and wishes to try using an existing model that was developed for another situation elsewhere, at a minimum it would be prudent to conduct validation tests of a number of candidate models by examining how well they predict recent travel behavior in the new location. Although the predictions from these models can usually be improved by adjusting the ASCs, it should be recognized that this may well be creating a false sense of confidence. What is more important is to ensure that the effects of differences in the continuous variables are properly reflected in the model predictions. If the prediction errors are reasonably consistent for each mode across all subsets of the data (e.g., by distance from the airport or across different income levels or air trip duration), then it is more likely that the model is reflecting the underlying behavior. On the other hand, even if the model correctly predicts the total number of trips using each mode but predictions for subsets of the data are wildly off, then it is very unlikely that the model will produce reasonable predictions of the likely effect of changes in the system.

CHAPTER EIGHT

INTEGRATION OF AIRPORT GROUND ACCESS MODELS IN REGIONAL PLANNING PROCESS

Although modeling airport access mode choice by air passengers and, to a lesser extent airport employees, has largely been restricted to specialized studies addressing airport landside and system planning issues, there is a growing interest in explicitly modeling such trips in the regional transportation planning process. As indicated in the survey responses discussed in chapter three, a number of MPOs have begun to address air passenger trips using a special-purpose mode choice model or special-generator sub-model and a somewhat smaller number of MPOs have begun to do the same for airport employee trips. However, a significant number continue to model trips to and from airports as regular regional travel using a standard trip classification, such as home-based non-work trips. Because these standard trip classifications encompass a very wide range of activities, most of which have very little in common with airport travel, it would be surprising if the model components did a very good job of predicting airport access mode choice. This is likely to be compounded because airport access and egress trips, by both air passengers and airport employees, typically have access to a much larger number of alternative modes than are usually modeled in regional travel demand models, such as shared-ride door-to-door van services and in some cases scheduled airport express bus services. Even taxi and limousine services, which account for a significant proportion of ground access trips at many airports, are typically not included as a separate mode in most regional travel models.

Furthermore, a significant fraction of all airport access and egress trips (as much as half or even greater at some tourist destinations) is made by visitors to the region. Most current regional travel models are only designed to model travel by residents of the region and largely ignore travel by visitors. Therefore, modes such as rental car and hotel courtesy shuttle are typically not included in the models. Although visitor trips have been considered in some activity-based microsimulation models (Bradley et al. 2001; Waddell et al. 2002) as well as in travel demand models for areas with a significant number of visitor trips, such as the Visitor Intra-CBD Model developed for the Central Area Loop Study for Cincinnati (Parsons Brinckerhoff 2001), the focus tends to be on the travel of visitors within the region rather than their travel to and from the airport. However, to the extent that intercity travel is increasing faster than intraregional travel, visitor trips will become a larger component of regional travel patterns, particularly in those areas that attract a large amount of tourist activity, and can be expected to attract greater interest in regional travel demand modeling.

Finally, the largest single air passenger access or egress mode at many airports, for both visitors and residents, is drop off and pick up by private vehicle. This option is also typically not explicitly modeled in regional travel models. Models predicting private vehicle use that are based on the assumption that the vehicle will be parked at the destination until the return trip will thus underestimate the vehicle-miles of travel involved by a factor of two.

These concerns may not be particularly important in terms of the total regional travel, because airport trips comprise a fairly small fraction of all regional trips, although it is unclear to what extent the errors tend to cancel each other out or are all in one direction. However, these issues become of much greater concern when the regional travel models are used to predict trips on parts of the transportation network in the vicinity of the airport or are used for airport access and egress studies, including predictions of airport access and egress trips for use in environmental documents.

Therefore, a fairly strong case can be made that airport access and egress trips need to be modeled separately from general regional travel patterns (or at least as a special-generator sub-model within the overall modeling framework) and then integrated with other trips in the traffic assignment process. This chapter discusses some of the issues that arise in integrating specialized airport access mode choice models into the general modeling framework and describes how these have been addressed by selected MPOs that have incorporated special-purpose airport access mode choice models or special-generator sub-models into their regional travel modeling process.

TECHNICAL CONSIDERATIONS

Most regional travel demand models are based on the well-established four-step approach of trip generation, trip distribution, mode choice, and traffic assignment, although not all regional models include all four components and implementation details differ widely (Vanasse Hangen Brustlin 2006). However, the regional travel demand models for most large metropolitan areas include all four components. Most models distinguish between home-based trips and non-home-based

trips and between work trips and non-work trips. For example, the regional travel demand model for the San Francisco Bay Area (*Baycast-90 Users Guide . . .* 2004) considers the following seven types of trip for intraregional personal travel:

- Home-based work
- Home-based shop/other
- Home-based social/recreational
- Home-based school (grade school)
- Home-based school (high school)
- Home-based school (college school)
- Non-home-based.

In addition, the model considers interregional personal trips and commercial (truck) trips, although projections of each of these two types of trip are generated by a separate analysis from that used to model intraregional personal travel.

Home-based work trips are synonymous with journey-to-work trips and cover travel in both directions to the extent that the modeling process considers travel outside the morning peak period. These trips would include the journey to work by airport employees. Air passenger travel would generally be included in home-based shop/other for airport access trips by area residents from their home and in non-home-based for airport access trips by area residents from other locations (e.g., their workplace) or visitor trips. Airport access trips by visitors to the area that start from the home of a relative or friend in the area should strictly also be included in home-based shop/other. However, the trip generation relationships for home-based trips do not typically consider trips by visitors to the household.

Given the very diverse trip purposes that will be included in home-based shop/other or non-home-based trips, any consideration of air passenger trips in the trip generation models is likely to be swamped by other types of trips. Perhaps of even greater concern, the distribution of those trips to destination zones in the trip distribution step of the modeling process is likely to be driven by measures of zonal attraction that take no account of the nature of airport trips. Thus, the number of airport trips generated by the normal modeling process will probably bear little or no relationship to the actual number of air party trips. Although the number of trips attracted to the airport zone can be adjusted to correspond to the actual level of airport traffic by using artificial values of the trip attraction variables (e.g., adjusting the amount of retail space assigned to the zone), this is obviously not a very satisfactory solution because the trips attracted to the airport zone are drawn away from the other zones and there is no guarantee that the resulting distribution of airport trip ends in the region will bear any relationship to reality. Indeed, because shopping trips are generally much shorter than airport access trips, this approach is likely to bias the distribution of airport access trip ends in favor of zones closer to the airport.

This suggests that airport access trips (at least air passenger trips) need to be modeled outside the general travel modeling process and the resulting vehicle trip tables between the access trip origin or the egress trip destination zones and the airport zones added in to the trip tables for other types of trips before the traffic assignment step. This will allow an appropriate mode choice model to be used for air passenger trips. Although air passenger survey data can provide the distribution of air passenger trip ends across the region, the fairly small sample sizes typically used in such surveys will produce a relatively "lumpy" distribution of air passenger trip ends and air party characteristics, with some analysis zones having no trip ends and others having air party trips with certain combinations of characteristics but not others. Therefore, it may be desirable to generate a much larger synthetic sample using Monte Carlo simulation techniques based on the distribution of air party characteristics in the survey results and measures of zonal socio-economic characteristics. This would require the development of an air passenger trip generation model that predicts the number of air passenger trip ends in each zone based on the zonal socio-economic characteristics (such as population, household income, commercial space, and hotel rooms). The Monte Carlo simulation would then generate a synthetic sample of trips of any desired size, assigning each trip to an analysis zone based on the distribution of trip ends from the trip generation model and assigning it air party characteristics by drawing randomly from an appropriate subset of the sample of air parties in the original survey.

The extent to which existing models of home-based work trip generation, distribution, and mode choice adequately account for airport employee travel is unclear and a potential subject for future research. However, it seems likely that any inaccuracy in the application of these models to airport employee travel will be much less significant than for air passenger travel.

CASE STUDIES

The following four case studies present a range of approaches that has been followed by different MPOs that have explicitly modeled airport trips in their regional travel modeling process. They have been chosen to illustrate a number of different ways in which airport trips can be integrated within the general regional travel modeling process. These approaches vary from a special-purpose sub-model within the travel modeling process of the ARC, through the external generation of airport trip tables that are combined with the trip tables generated by the regular travel modeling process of the MWCOG, to two examples of the use of external airport access mode choice models. In the case of the Boston CTPS, an air passenger mode choice model that has been described earlier in this report was developed in-house in cooperation with the airport authority. In contrast, the Southern California Association of Governments (SCAG)

utilizes a proprietary air passenger mode choice model, the output of which is then used as input to the regular regional travel modeling process.

Atlanta Regional Commission

The ARC is the MPO for the Atlanta region. The ARC has developed an APM as a component of its regional travel demand model (*Model Documentation . . .* 2005; *Travel Demand . . .* 2006). The ARC/APM enables air passenger travel to and from Atlanta Hartsfield–Jackson International Airport to be included in the overall regional travel modeling process. The details of the model are summarized in chapter three and presented in more detail in Appendix D (web version only) of this report.

The model is programmed in Fortran and can be called by the software used by the ARC to implement its regional travel demand model. This was originally programmed using Tranplan software, but has recently been converted to TP+/Cube Voyager software. The program reads highway and transit travel times and costs from standard TP+/Cube skim files and generates binary trip tables of transit passenger and vehicle trips in TP+/Cube Voyager format that can be combined with trip tables generated by the regional travel demand model for other types of trips before assigning passenger trips to the transit network and vehicle trips to the highway network in the final step of the regional travel demand modeling process.

Boston Central Transportation Planning Staff

CTPS is the MPO for the Boston metropolitan area. With support from Massport, CTPS developed an air passenger airport access mode choice model for use in a range of airport ground transportation planning studies at Boston Logan Airport. The details of the model are summarized in chapter three and presented in more detail in Appendix D (web version only) of this report.

The model is run separately from the regional travel demand model to generate estimates of air passenger and vehicle trips by regional TAZ. These trip tables are then used to include the air passenger trips in the regional transit assignment model and the vehicle trips in the regional highway assignment model as the last pre-assignment step in the CTPS Regional Travel Forecasting Model Set for Eastern Massachusetts (Harrington 2003).

Metropolitan Washington Council of Governments

MWCOG is the MPO for the Baltimore–Washington metropolitan area, which includes three large commercial service airports: Ronald Reagan Washington National Airport, Washington Dulles International Airport, and Baltimore–Washington International Airport. MWCOG conducts periodic air passenger surveys at the three airports to obtain information for use in its aviation system planning and regional travel demand modeling activities. The most recent survey was undertaken in 2005 (*2005 Washington–Baltimore . . .* 2006a).

The MWCOG travel demand modeling process distinguishes between "modeled" trips and "non-modeled" trips (*FY-2003 Models . . .* 2003). Modeled trips are those estimated from the traditional four-step transportation planning process and are based on travel data obtained from household travel surveys. Although these trips may include some air passenger trips, to the extent that households may have recorded air travel trips in the household travel survey, most air passenger trips will not be reflected in the modeled trips. Non-modeled trips are those types of trips that will not be reflected in the household travel surveys, such as trips by visitors to the region or many air passenger trips. Therefore, MWCOG estimates air passenger trip tables from the air passenger survey data outside the travel demand modeling process, converts air passenger trips to vehicle trips, divides these trip tables into the three time-of-day periods used in the regional travel demand model (a.m. peak, p.m. peak, and off-peak), and then combines the resulting vehicle trip tables with those for modeled trips and other types of non-modeled trips (such as taxi trips or trips passing through the region) before the traffic assignment step of the modeling process.

Because the MWCOG regional travel modeling process is based on an average weekday, the results of the air passenger survey are first converted into average weekday enplanements. The resulting pattern of access trips is then transposed to give the pattern of egress trips and the two trip tables are added together to give the flow in both directions. These are then divided into the time-of-day trip tables by assuming that 10% of the air passenger trips occur in the a.m. peak period and another 10% in the p.m. peak period. The projection of these trip tables to future years uses a Fratar-based approach that initially applies growth factors at the airport end of the trip based on forecasts of airport enplanements and growth factors at the other ends of the trip based on regional forecasts of households and employment and then iteratively balances the resulting flows (*FY-2006 Development . . .* 2006).

MWCOG has established the goal of improving the representation of special traffic generators, including airports, and has begun the process of developing a more formal model of airport access demand, including potentially an airport choice component (*FY-2003 Models . . .* 2003; *FY-2005 Development . . .* 2005; *FY-2006 Development . . .* 2006). As part of this effort, MWCOG staff undertook a review of airport access and airport choice modeling in eight large metropolitan regions (*FY-2003 Models . . .* 2003). The findings of this review largely parallel the information presented in this report, although some additional detail is provided on the modeling approach in some of the metropolitan areas. In particular, the

review addresses airport choice modeling, which is outside the scope of this report.

Southern California Association of Governments

SCAG is the MPO for the six-county Southern California region that includes the Los Angeles basin and contains six primary commercial service airports with significant levels of airline service and several secondary commercial service airports that have some regional airline service or support air cargo activity. Since the early 1990s, SCAG has made use of a proprietary air travel demand forecasting model called the Regional Airport Demand Allocation Model (RADAM) to support its aviation planning activities (Southern California Association of Governments 2002). Although the model is primarily designed to allocate regional air travel demand to airports, it contains an airport access mode choice component and can predict vehicle trips by different modes from each analysis zone to each airport in the region. The model has undergone a number of extensions and enhancements over the years and, in addition to air passenger travel, the current version has the capability of modeling the distribution of air cargo demand among airports in the region and can consider the effect of airport capacity constraints on the allocation of demand among airports. It can also estimate vehicle-miles of highway travel resulting from airport access and egress trips and the associated vehicle emissions. However, the published documentation on RADAM is fairly limited and does not include many technical details on the model form or structure. In particular, there is very little information on the ground access mode choice component of the model.

The analysis zones used in the model (called RADAM zones) consist of aggregations of SCAG TAZs, with approximately 3,000 SCAG TAZs grouped into approximately 100 RADAM zones. This would make it difficult to directly integrate the results of the RADAM analysis into the regional travel demand model trip assignment process and that does not appear to be how the model is used. Rather, the model is run as an entirely separate activity and the aggregate results (e.g., vehicle-miles of travel and vehicle emissions) are added to the regional travel demand model results for other types of trips.

CHAPTER NINE

CONCLUSIONS AND FURTHER RESEARCH

Airport ground access and egress mode choice models play a critical role in airport landside planning studies and modeling traffic on the regional transportation system in the vicinity of airports. The ability to predict how air passenger and airport employee access and egress mode use will change in response to changes in the airport landside access system or other anticipated changes in the regional transportation system is essential to the proper evaluation of proposed measures and projects. However, these decisions are influenced by very different factors from those affecting general regional travel patterns and the range of transportation options available to airport travelers are often quite different from those for other types of regional trips. Therefore, there is a need for specialized models that can represent these mode choice decisions as well as the means to integrate these models or their output into the regional traveling modeling process.

Aside from the need to predict ground access mode use at a given airport, air passenger ground access mode choice also affects airport choice in regions served by multiple commercial airports. The relative accessibility of each airport is one of the key determinants in air passenger choice of airport (together with the air service offered at each airport) and for any given traveler the accessibility of an airport is influenced not only by the driving time needed to reach it, but also by the alternative ground transportation options that are available. In those cases where regional planners or local airport authorities wish to encourage the use of secondary airports serving the region, or to explore the feasibility of constructing a new airport, improvements to the ground access system may be one way to influence air passenger choice of airports and in turn the willingness of airlines to provide or expand air service at those airports.

As a result, the development of air passenger ground access mode choice models has been the subject of ongoing research for more than 30 years. Over this period, the state of practice has slowly evolved from relatively simple multinomial logit models to more complex nested logit models involving several levels of nesting and four or more market segments. However, no clear consensus has yet emerged as to what explanatory variables should be included or how the various modes and sub-modes should be nested. In addition, even the most recent models still have not addressed a number of problematic issues in a meaningful way. These include how to treat rental car use by non-residents of a region who often rent a car to meet local travel needs other than the airport egress and later return access trip, and how best to account for the role of household income in the mode choice process.

In addition to these technical considerations, there has been almost no attention given to how reliably existing models predict air passenger access mode use when circumstance change from those prevailing when the model development data were collected. However, because the models are typically used to predict mode use under very different conditions, including changes in the physical infrastructure or ground transportation services, there is a pressing need for more research into this aspect, as well as continuing research directed at improving the current state of practice.

In contrast to air passenger mode choice models, there has been very little effort directed at developing airport employee mode choice models. The majority of metropolitan planning organizations model airport employee trips the same way as they model any other journey-to-work trips, if indeed they model them at all. The development of better airport employee access models is a promising research opportunity.

Finally, many existing regional travel models do not explicitly model airport trips, but treat them as general regional travel. Because of the unique characteristics of airport travel and the range of transportation options typically available at airports, this is likely to give fairly poor predictions of airport mode use and the resulting vehicle trips. However, the likely magnitude of the error is not clear. Further research is needed to explore how well existing regional travel models account for airport trips and to provide guidance on how best to implement explicit modeling of airport access mode choice in the regional travel modeling process.

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GLOSSARY

Air party—group of air passengers traveling together.

Airport access trip—travel by air passengers, airport employees, or others to an airport from their home or other local trip origin.

Airport egress trip—travel by air passengers, airport employees, or others from an airport to their home or other destination.

Alternative-specific constant (ASC)—constant term in the utility function for a specific mode in a mode choice model that reflects the attributes of the mode that are not accounted for by the other variables in the utility function.

Calibration—see model calibration.

Causal variable—factor that is believed to influence the outcome of some process, such as a characteristic of a decision maker or a measure of the situation faced by that decision maker that influences the decision that is made.

Coefficient—terms in a model that assume fixed values and interact with the independent variables to predict the value of the dependent variable.

Composite alternative—an alternative in a choice model (typically a nested choice model) that represents the combined effect of several discrete sub-choices.

Continuous variable—variable in the utility function for a specific mode in a mode choice model (or indeed a variable in any model) that can assume any appropriate value.

Dependent variable—term in a model the values for which are predicted by the model based on the values of the independent variables.

Deplanements—number of passengers getting off aircraft at an airport.

Disaggregate choice model—model explaining the choice made by an individual (or group of individuals) in terms of the characteristics of that individual or group and the prevailing conditions under which the choice was made.

Dummy variable—variable that can only take the value zero or one.

Enplanements—number of passengers boarding aircraft at an airport.

Estimation—see model estimation.

Explanatory variable—independent variable describing some external factor or attribute of the process being modeled that is believed to influence or has been shown to influence the outcome of the process being modeled.

Independent variable—term in a model that can take values that can be varied independently of the values of other terms in the model.

Logarithmic transformation—conversion of a variable to the logarithm (usually the natural logarithm) of its value.

Logit model—particular form of mathematical model describing the probability of choosing an alternative from among a set of possible choices, in which the natural logarithm of the ratio of the probability of choosing one alternative to that of choosing a second alternative is equal to the difference in the value of the utility functions of the two alternatives.

Mode choice—process by which a traveler chooses the mode of transportation to use for a trip.

Mode of transportation—specific form of transportation (e.g., automobile, taxi, and public transit).

Model calibration—process of adjusting the formulation or parameters of a model so that the predictions of the model correspond to an observed outcome of the process being modeled.

Model estimation—process of determining the values of the parameters of a model that result in the model giving the best fit to a given set of data describing the process being modeled.

Monte Carlo simulation—an analysis technique in which a series of pseudo-random numbers are generated by a computer program (pseudo-random because numbers generated by a computer program cannot be truly random) and then used to select values from one or more defined statistical distributions to generate a new dataset that conforms to the statistical distribution(s).

Multinomial logit (MNL) model—form of logit model with more than two choice alternatives in which all the alternatives enter into the choice process at the same level.

Nested logit (NL) model—form of logit model in which some choice alternatives are considered to enter into the choice process as sub-choices of a higher-level choice alternative.

Originations—number of passengers boarding aircraft at an airport who have traveled to the airport by ground and are starting their directional air trip.

Pivot-point analysis—a technique in which the coefficients of a mode choice model are used to predict the proportional change in mode share from a change in some transportation service variable and then this proportional change is applied to the existing mode share to predict the new mode share.

Revealed preference model—model of behavioral choice process estimated from data on choices actually made by subjects together with data on factors believed to influence their choice process and descriptive data on alternatives available to subjects from which they made their choices.

Stated preference model—model of behavioral choice process estimated from data in which subjects select options from among hypothetical sets of alternatives for which they have been provided with comparative descriptive data.

Utility function—mathematical expression combining the effect of several causal variables into a single measure of the perceived attractiveness of a given alternative within a set of possible choices.

APPENDIX A

Survey Questionnaires

Four versions of the survey questionnaire were prepared to tailor the questions to the four types of organizations that become involved in airport ground access modeling:

- Airport Authorities
- Metropolitan Planning Organizations
- Airport Planning Consultants and Research Organizations
- State and Federal Government and Industry Organizations

Each of these questionnaires is shown in turn on the following pages.

TRB

ACRP SYNTHESIS SURVEY

Airport Ground Access Mode Choice Models

Airport Authority Survey

Survey purpose: This survey is being performed as part of a study by the Airport Cooperative Research Program (ACRP) to document the state-of-the-practice in airport ground access mode choice models. Formal models of airport ground access mode choice form a key analytical component of airport landside planning, as well as airport system planning, and are used to predict how airport users will change their access or egress mode in response to changes in the airport ground transportation system (such as changes in fares, rates, or service levels) or the introduction of new modes (such as the extension of a light rail system to the airport). Airport access trips are different from the typical trip accounted for in regional transportation planning models. Therefore, it is difficult to determine the economic feasibility of proposed projects to improve airport ground transportation or effectively manage the existing airport ground transportation system using traditional regional travel forecasting models. However, models designed to address airport ground access travel decisions are highly specialized and their technical details are often not well understood by airport managers and planners. The purpose of this survey is to gather information on the use of such models by airports and other organizations.

The final report, to be published by the Transportation Research Board, will document the technical details of existing airport ground access mode choice models together with agency assessments of their effectiveness and reliability. This report will be extremely useful to all airports and other agencies involved in airport ground transportation planning as they consider how best to analyze the effect of changing conditions and circumstances on how air passengers, airport employees, and other airport users decide to travel to and from the airport. All survey responses will be confidential.

Thank you for taking the time to participate. Instructions on returning the survey are included on the last page.

This form can be completed by typing information in the fill-in text fields and clicking the check boxes to check them. Save the file when done and return by e-mail. Alternatively, the form can be printed, filled in by hand, and returned by fax or mail.

RESPONDENT INFORMATION

Date: _____

Name and Title of Respondent: _____

Agency Name: _____

Respondent Telephone Number: _____

Respondent e-Mail Address: _____

AIRPORT GROUND ACCESS STUDIES

1. Has your airport undertaken or commissioned any studies in **the past 10 years** that have included some analysis of airport **ground access mode choice**?
   - ☐ Yes. *Please provide title of study or studies (add lines as necessary).*
     1. _____
     2. _____
     3. _____
   - ☐ No (*Skip to Q.8*)

2. Did any of these studies make use of formal **analytical models** of airport ground access mode choice?
   - ☐ Yes. *Please indicate which (using numbers from Q.1)*: _____
   - ☐ No (*Skip to Q.7*)

3. Are reports from any of these studies available on your organization's website?
   - ☐ Yes. *Please provide website address:* _____
   - ☐ No

4. What was the source of air passenger survey data used in the development of these airport ground access mode choice models? (*Please check all that apply.*)
   - ☐ Surveys performed specifically for the model development
   - ☐ Surveys performed for other purposes
   - ☐ Don't know

5. Are reports on any of these surveys available on your organization's website?
   - ☐ Yes. *Please provide website address:* _____
   - ☐ No

6. Based on your agency's past experience with airport ground access mode choice models, how would you characterize the current state-of-practice? (*Please check all that apply.*)
   - ☐ Adequate for our needs
   - ☐ Predictions from existing models are not reliable enough
   - ☐ Available models are too complex to use
   - ☐ Models are too costly to use except for very large studies

   Please skip to Q.8

7. What was the reason that these studies did not include any analytical modeling of airport ground access mode choice? (*Please check all that apply.*)
   - ☐ Scope of studies did not require it
   - ☐ Available models are not reliable enough
   - ☐ Available models are too difficult to use
   - ☐ There is a lack of information and guidance on the use of such models
   - ☐ Decision on analytical techniques to use was made by those performing the studies
   - ☐ Don't know

8. Has your airport undertaken or commissioned any studies **prior to** the last 10 years that made use of formal analytical models of airport ground access?
   - ☐ Yes
   - ☐ No
   - ☐ Not sure

AIRPORT CHOICE STUDIES

9. Has your airport undertaken or commissioned any studies **in the past 10 years** that have included some analysis of air passenger **airport choice**?
   - ☐ Yes. *Please provide title of study or studies (add lines as necessary).*
     1. _____
     2. _____
     3. _____
   - ☐ No (*Skip to Q.11*)

10. Did any of these studies make use of analytical techniques that took **airport ground access mode choice** into consideration as a factor in airport choice?
    - ☐ Yes. *Please indicate which (using numbers from Q.9):* _____
    - ☐ No

STUDIES BY OTHER ORGANIZATIONS

11. Are you aware of any other airports or organizations that have made use of formal analytical models of airport ground access mode choice in the course of studies or analysis addressing airport ground transportation or airport choice?
    - ☐ Yes. *Please provide name of organization(s) (list up to three).*
      1. _____
      2. _____
      3. _____
    - ☐ No

GENERAL COMMENTS

12. Please feel free to add any comments about airport ground access mode choice models in general or the scope of this ACRP study in particular:

_____

_____

_____

_____

_____

Please return by **February 23, 2007** to:

Geoffrey Gosling
Principal
Aviation System Consulting, LLC
805 Colusa Avenue
Berkeley, CA 94707
phone: (510) 528-8741
fax: (510) 528-8745
e-mail gdgosling@aol.com

We encourage you to return your completed survey via e-mail. If you have any questions on the survey or the project, feel free to contact Geoff Gosling by e-mail or phone.

THANK YOU FOR YOUR HELP

TRB

ACRP SYNTHESIS SURVEY

Airport Ground Access Mode Choice Models

Metropolitan Planning Organization Survey

Survey purpose: This survey is being performed as part of a study by the Airport Cooperative Research Program (ACRP) to document the state-of-the-practice in airport ground access mode choice models. Formal models of airport ground access mode choice form a key analytical component of airport landside planning, as well as airport system planning, and are used to predict how airport users will change their access or egress mode in response to changes in the airport ground transportation system (such as changes in fares, rates, or service levels) or the introduction of new modes (such as the extension of a light rail system to the airport). Airport access trips are different from the typical trip accounted for in regional transportation planning models. Therefore, it is difficult to determine the economic feasibility of proposed projects to improve airport ground transportation or effectively manage the existing airport ground transportation system using traditional regional travel forecasting models. However, models designed to address airport ground access travel decisions are highly specialized and their technical details are often not well understood by airport managers and planners. The purpose of this survey is to gather information on the use of such models by airports and other organizations.

The final report, to be published by the Transportation Research Board, will document the technical details of existing airport ground access mode choice models together with agency assessments of their effectiveness and reliability. This report will be extremely useful to all airports and other agencies involved in airport ground transportation planning as they consider how best to analyze the effect of changing conditions and circumstances on how air passengers, airport employees, and other airport users decide to travel to and from the airport. All survey responses will be confidential.

Thank you for taking the time to participate. Instructions on returning the survey are included on the last page.

This form can be completed by typing information in the fill-in text fields and clicking the check boxes to check them. Save the file when done and return by e-mail. Alternatively, the form can be printed, filled in by hand, and returned by fax or mail.

RESPONDENT INFORMATION

Date: _____

Name and Title of Respondent: _____

Agency Name: _____

Respondent Telephone Number: _____

Respondent e-Mail Address: _____

AIRPORT GROUND ACCESS STUDIES

1. Has your agency undertaken or commissioned any studies in **the past 10 years** that have included some analysis of airport **ground access mode choice**, apart from your normal travel demand modeling activities?

   ☐ Yes. *Please provide title of study or studies (add lines as necessary).*

   4. _____
   5. _____
   6. _____

   ☐ No (*Skip to Q.9*)

2. Did any of these studies make use of formal **analytical mode choice models** for airport ground access trips?

   ☐ Yes. *Please indicate which (using numbers from Q.1)*: _____

   ☐ No (*Skip to Q.8*)

3. Were these mode choice models specifically developed for airport ground access travel or did you use or adapt mode choice models for general urban travel behavior? (*Please check all that apply.*)
   - ☐ Studies used special-purpose airport ground access mode choice models
   - ☐ Studies adapted special-generator sub-models designed for other types of trips
   - ☐ Studies adapted mode choice models for general urban travel to airport trips
   - ☐ Studies used mode choice models for general urban travel for airport trips

4. Are reports from any of these studies available on your organization's website?
   - ☐ Yes. *Please provide website address:* _____
   - ☐ No

5. What was the source of air passenger survey data (if any) used in the development of the mode choice models for airport ground access travel? (*Please check all that apply.*)
   - ☐ Surveys performed specifically for the model development
   - ☐ Surveys performed for other purposes by this agency
   - ☐ Surveys performed for other purposes by another agency
   - ☐ No survey data used in the development of the models
   - ☐ Don't know

6. Are reports on any of these surveys available on your organization's website?
   - ☐ Yes. *Please provide website address:* _____
   - ☐ No

7. Based on your agency's past experience with airport ground access mode choice models, how would you characterize the current state-of-practice? (*Please check all that apply.*)
   - ☐ Adequate for our needs
   - ☐ Predictions from existing models are not reliable enough
   - ☐ Available models are too complex to use
   - ☐ Models are too costly to use except for very large studies

   Please skip to Q.9

8. What was the reason that these studies did not include any analytical modeling of airport ground access mode choice? (*Please check all that apply.*)
   - ☐ Scope of studies did not require it
   - ☐ Available models are not reliable enough
   - ☐ Available models are too difficult to use
   - ☐ There is a lack of information and guidance on the use of such models
   - ☐ Decision on analytical techniques to use was made by those performing the studies
   - ☐ Don't know

9. Has your agency undertaken or commissioned any studies **prior to** the last 10 years that made use of formal analytical models of airport ground access?
   - ☐ Yes
   - ☐ No
   - ☐ Not sure

10. How do you model airport trips in your general regional travel modeling process? (*Please check all that apply.*)
    - ☐ Use a special-generator sub-model for air passenger trips
    - ☐ Use a special-generator sub-model for airport employee trips
    - ☐ Treat air passenger trips the same way as other home-based non-work trips
    - ☐ Treat air passenger trips the same way other non-home-based non-work trips
    - ☐ Treat airport employee trips the same way as other journey-to-work trips
    - ☐ Do not consider airport trips in regional travel modeling process
    - ☐ Other (*Please describe*): _____

      _____

AIRPORT CHOICE STUDIES

11. Has your agency undertaken or commissioned any studies **in the past 10 years** that have included some analysis of air passenger **airport choice**?

☐ Yes. *Please provide title of study or studies (add lines as necessary).*

1. _____
2. _____
3. _____

☐ No (*Skip to Q.13*)

12. Did any of these studies make use of analytical techniques that took **airport ground access mode choice** into consideration as a factor in airport choice?

☐ Yes. *Please indicate which (using numbers from Q.11)*: _____

☐ No

STUDIES BY OTHER ORGANIZATIONS

13. Are you aware of any **other** planning agencies, airports, or organizations that have made use of formal analytical models of airport ground access mode choice in the course of studies or analysis addressing airport ground transportation or airport choice?

☐ Yes. *Please provide name of organization (list up to three).*

1. _____
2. _____
3. _____

☐ No

GENERAL COMMENTS

14. Please feel free to add any comments about airport ground access mode choice modes in general or the scope of this ACRP study in particular.

_____

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_____

Please return by **February 23, 2007** to:

Geoffrey Gosling
Principal
Aviation System Consulting, LLC
805 Colusa Avenue
Berkeley, CA 94707
phone: (510) 528-8741
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THANK YOU FOR YOUR HELP

TRB

ACRP SYNTHESIS SURVEY

Airport Ground Access Mode Choice Models

Consulting Firm and Research Organization Survey

Survey purpose: This survey is being performed as part of a study by the Airport Cooperative Research Program (ACRP) to document the state-of-the-practice in airport ground access mode choice models. Formal models of airport ground access mode choice form a key analytical component of airport landside planning, as well as airport system planning, and are used to predict how airport users will change their access or egress mode in response to changes in the airport ground transportation system (such as changes in fares, rates, or service levels) or the introduction of new modes (such as the extension of a light rail system to the airport). Airport access trips are different from the typical trip accounted for in regional transportation planning models. Therefore, it is difficult to determine the economic feasibility of proposed projects to improve airport ground transportation or effectively manage the existing airport ground transportation system using traditional regional travel forecasting models. However, models designed to address airport ground access travel decisions are highly specialized and their technical details are often not well understood by airport managers and planners. The purpose of this survey is to gather information on the use of such models by airports and other organizations.

The final report, to be published by the Transportation Research Board, will document the technical details of existing airport ground access mode choice models together with agency assessments of their effectiveness and reliability. This report will be extremely useful to all airports and other agencies involved in airport ground transportation planning as they consider how best to analyze the effect of changing conditions and circumstances on how air passengers, airport employees, and other airport users decide to travel to and from the airport. All survey responses will be confidential.

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RESPONDENT INFORMATION

Date: _____

Name and Title of Respondent: _____

Organization: _____

Respondent Telephone Number: _____

Respondent e-Mail Address: _____

AIRPORT GROUND ACCESS STUDIES

1. Have you or your organization undertaken or participated in any studies in **the past 10 years** that have included some analysis of airport **ground access mode choice**?

☐ Yes. How many? _____

Please provide name of study sponsor and title of the most recent study or studies (list up to six).

1. Sponsor: _____
   Study: _____
2. Sponsor: _____
   Study: _____
3. Sponsor: _____
   Study: _____
4. Sponsor: _____
   Study: _____
5. Sponsor: _____
   Study: _____
6. Sponsor: _____
   Study: _____

☐ No (*Skip to Q.8*)

2. Did any of these studies make use of formal **analytical models** of airport ground access mode choice?
   - ☐ Yes. *Please indicate which (using numbers from Q.1)*: _____
   - ☐ No (*Skip to Q.7*)

3. Are reports from any of these studies available on your or another organization's website?
   - ☐ Yes. *Please provide website address:* _____
   - ☐ No

4. What was the source of **air passenger survey data** used in the development of these airport ground access mode choice models? (*Please check all that apply.*)
   - ☐ Surveys performed specifically for the model development
   - ☐ Surveys performed for other purposes
   - ☐ Don't know

5. Are reports on any of these surveys available on your or another organization's website?
   - ☐ Yes. *Please provide website address:* _____
   - ☐ No

6. Based on your organization's past experience with airport ground access mode choice models, how would you characterize the current state-of-practice? (*Please check all that apply.*)
   - ☐ Adequate for our needs
   - ☐ Predictions from existing models are not reliable enough
   - ☐ Available models are too complex to use
   - ☐ Models are too costly to use except for very large studies

   Please skip to Q.8

7. What was the reason that these studies did not include any analytical modeling of airport ground access mode choice? (*Please check all that apply.*)
   - ☐ Scope of studies did not require it
   - ☐ Available models are not reliable enough
   - ☐ Available models are too difficult to use
   - ☐ There is a lack of information and guidance on the use of such models
   - ☐ Decision on analytical techniques to use was made by those performing the studies
   - ☐ Don't know

AIRPORT CHOICE STUDIES

8. Have you or your organization undertaken or participated in any studies **in the past 10 years** that have included some analysis of air passenger **airport choice**?
   - ☐ Yes. How many? _____

     Please provide name of study sponsor and title of the most recent study or studies (list up to three).

     1. Sponsor: _____
        Study: _____
     2. Sponsor: _____
        Study: _____
     3. Sponsor: _____
        Study: _____
   - ☐ No (*Skip to Q.11*)

9. Did any of these studies make use of analytical techniques that took **airport ground access mode choice** into consideration as a factor in airport choice?
   - ☐ Yes. *Please indicate which (using numbers from Q.8)*: _____
   - ☐ No

STUDIES BY OTHER ORGANIZATIONS

10. Are you aware of any **other** organizations that have made use of formal analytical models of airport ground access mode choice in the course of studies or analysis addressing airport ground transportation or airport choice?

☐ Yes. *Please provide name of organization(s) (list up to three).*

4. _____

5. _____

6. _____

☐ No

GENERAL COMMENTS

11. Please feel free to add any comments about airport ground access mode choice models in general or the scope of this ACRP study in particular:

_____

_____

_____

_____

_____

Please return by **February 23, 2007** to:

Geoffrey Gosling
Principal
Aviation System Consulting, LLC
805 Colusa Avenue
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THANK YOU FOR YOUR HELP

TRB

ACRP SYNTHESIS SURVEY

Airport Ground Access Mode Choice Models

Government and Industry Organization Survey

Survey purpose: This survey is being performed as part of a study by the Airport Cooperative Research Program (ACRP) to document the state-of-the-practice in airport ground access mode choice models. Formal models of airport ground access mode choice form a key analytical component of airport landside planning, as well as airport system planning, and are used to predict how airport users will change their access or egress mode in response to changes in the airport ground transportation system (such as changes in fares, rates, or service levels) or the introduction of new modes (such as the extension of a light rail system to the airport). Airport access trips are different from the typical trip accounted for in regional transportation planning models. Therefore, it is difficult to determine the economic feasibility of proposed projects to improve airport ground transportation or effectively manage the existing airport ground transportation system using traditional regional travel forecasting models. However, models designed to address airport ground access travel decisions are highly specialized and their technical details are often not well understood by airport managers and planners. The purpose of this survey is to gather information on the use of such models by airports and other organizations.

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RESPONDENT INFORMATION

Date: _____

Name and Title of Respondent: _____

Agency Name: _____

Respondent Telephone Number: _____

Respondent e-Mail Address: _____

AIRPORT GROUND ACCESS STUDIES

1. Has your organization undertaken or commissioned any studies in **the past 10 years** that have included some analysis of airport **ground access mode choice**?
   - ☐ Yes. *Please provide title of study or studies (add lines as necessary).*
     - 7. _____
     - 8. _____
     - 9. _____
   - ☐ No (*Skip to Q.8*)

2. Did any of these studies make use of formal **analytical models** of airport ground access mode choice?
   - ☐ Yes. *Please indicate which (using numbers from Q.1)*: _____
   - ☐ No (*Skip to Q.7*)

3. Are reports from any of these studies available on your organization's website?
   - ☐ Yes. *Please provide website address:* _____
   - ☐ No

4. What was the source of **air passenger survey data** used in the development of these airport ground access mode choice models? (*Please check all that apply.*)
   - ☐ Surveys performed specifically for the model development
   - ☐ Surveys performed for other purposes
   - ☐ Don't know

5. Are reports on any of these surveys available on your organization's website?
   - ☐ Yes. *Please provide website address:* _____
   - ☐ No

6. Based on your organization's past experience with airport ground access mode choice models, how would you characterize the current state-of-practice? (*Please check all that apply.*)
   - ☐ Adequate for our needs
   - ☐ Predictions from existing models are not reliable enough
   - ☐ Available models are too complex to use
   - ☐ Models are too costly to use except for very large studies

   Please skip to Q.8

7. What was the reason that these studies did not include any analytical modeling of airport ground access mode choice? (*Please check all that apply.*)
   - ☐ Scope of studies did not require it
   - ☐ Available models are not reliable enough
   - ☐ Available models are too difficult to use
   - ☐ There is a lack of information and guidance on the use of such models
   - ☐ Decision on analytical techniques to use was made by those performing the studies
   - ☐ Don't know

AIRPORT CHOICE STUDIES

8. Has your organization undertaken or commissioned any studies **in the past 10 years** that have included some analysis of air passenger **airport choice**?
   - ☐ Yes. *Please provide title of study or studies (add lines as necessary).*
     4. _____
     5. _____
   - ☐ No (*Skip to Q.10*)

9. Did any of these studies make use of analytical techniques that took **airport ground access mode choice** into consideration as a factor in airport choice?
   - ☐ Yes. *Please indicate which (using numbers from Q.8):* _____
   - ☐ No

STUDIES BY OTHER ORGANIZATIONS

10. Are you aware of any airports or other organizations that have made use of formal analytical models of airport ground access mode choice in the course of studies or analysis addressing airport ground transportation or airport choice?
    - ☐ Yes. *Please provide name of study sponsor and title of study (list up to five).*
      7. Sponsor: _____
         Study: _____
      8. Sponsor: _____
         Study: _____
      9. Sponsor: _____
         Study: _____

10. Sponsor: _____
    Study: _____
11. Sponsor: _____
    Study: _____

☐ No

GENERAL COMMENTS

11. Please feel free to add any comments about airport ground access mode choice models in general or the scope of this ACRP study in particular:

_____

_____

_____

_____

_____

Please return by **February 23, 2007** to:

Geoffrey Gosling
Principal
Aviation System Consulting, LLC
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phone: (510) 528-8741
fax: (510) 528-8745
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THANK YOU FOR YOUR HELP

APPENDIX B

Summary of Survey Results

The following tables (B1–B6) summarize the responses to the survey questions by type of responding organization. Where more than one individual responded from a given organization, their responses have generally been combined in the following statistics. For ease of reference, the question numbers in the tables generally follow the numbering in the Airport Authority survey questionnaire. The corresponding questions may have different numbers in the questionnaires for other types of organizations owing to the addition of questions specific to each type of organization. The two questions that were specific to metropolitan planning organizations are numbered with their original number in the relevant questionnaire.

TABLE B1
AIRPORT GROUND ACCESS STUDIES

	Airport Authorities	MPOs	State/Fed Government	Consulting Firms	Research	**Total**	Percent
Survey Responses (organizations)	32	24	19	23	7	**105**	
Q.1: Number reporting ground access studies	21	8	2	20	6	**57**	54%
Number of studies identified	24	11	7	43	10	**95**	
Unduplicated						85	
Q2: Number reporting mode choice model use	8	5	2	13	6	**34**	*60%*[a]
Number of studies identified	12	7	7	23	9	**58**	
Unduplicated						52	
Q3: Study reports available on web	1	2	0	0	2	**5**	*15%*[b]

Notes: a) Percent of organizations reporting ground access studies
b) Percent of organizations reporting use of mode choice models

TABLE B2
AIRPORT ACCESS MODE CHOICE MODEL DEVELOPMENT AND USE

	Airport Authorities	MPOs	State/Fed Government	Consulting Firms	Research	**Total**	Percent
Number reporting mode choice model use	8	5	2	13	6	**34**	
Q.4: Source of air passenger survey data							*Of those using models*
Model development	6	2	1	9	5	**23**	*68%*
Other purposes	4	3	2	10	4	**23**	*68%*
Don't know	0	0	0	0	0	**0**	
Q.5: Survey reports available on web	1	0	0	2	2	**5**	*15%*
Q.7: Reasons modeling not used (where not)							*Of those not using models*
Number reporting	12	3		7		**22**	
Not required	8	1		6		**15**	*68%*
Not reliable enough	-	2	*all reported model use*	-	*all reported model use*	**2**	*9%*
Too difficult to use	-	1		-		**1**	*5%*
Lack of guidance	-	2		2		**4**	*18%*
Decided by others	2	-		-		**2**	*9%*
Don't know	2	-		1		**3**	*14%*

TABLE B3
CURRENT STATE OF PRACTICE WITH AIRPORT ACCESS MODE CHOICE MODELS

	Airport Authorities	MPOs	State/Fed Government	Consulting Firms	Research	**Total**	Percent
Number reporting mode choice model use	8	5	2	13	6	**34**	
Q.6 Assessment of current state of practice							
Adequate for needs	7	5	-	5	2	**19**	*56%*
Not reliable enough	1	-	1	6	4	**12**	*35%*
Too complex to use	-	-	1	2	-	**3**	*9%*
Too costly to use	2	-	1	5	2	**10**	*29%*

TABLE B4
STUDIES INVOLVING AIRPORT ACCESS MODE CHOICE MODELS PRIOR TO LAST TEN YEARS

	Airport Authorities	MPOs	**Total**	Percent
Survey responses to question	31	24	**55**	
Q.8 Prior studies using mode choice modeling				
Yes	4	5	**9**	*16%*
No	15	14	**29**	*53%*
Not sure	12	5	**17**	*31%*

TABLE B5
STUDIES OF AIR PASSENGER AIRPORT CHOICE

	Airport Authorities	MPOs	State/Fed Government	Consulting Firms	Research	**Total**	Percent
Survey responses (organizations)	32	24	19	23	7	**105**	
Q.9: Number reporting airport choice studies	13	2	6	14	2	**37**	35%
Number of studies identified	11	4	3	13	3	**34**	
Unduplicated						32	
Q10: Number reporting mode choice model use	5	1	1	6	2	**15**	*41%*
Number of studies identified	4	3	1	5	3	**16**	
Unduplicated						16	

Note: Some respondents reported involvement in airport choice studies or use of mode choice models but did not identify specific studies

TABLE B6
MODELING AIRPORT ACCESS TRIPS IN REGIONAL TRANSPORTATION PLANNING

	MPOs	Percent
Number responding to Question 3 (MPO performed study using airport access mode choice model)	5	
Q.3 (MPO) Type of model used		*(a)*
Special purpose airport access model	4	*80%*
Adapted special-generator model	1	*20%*
Adapted general urban travel model	—	
Used general urban travel model	1	*20%*
Number responding to Question 10 (all MPO respondents)	24	
Q.10 (MPO) How airport trips are modeled in general regional travel modeling process		*(b)*
Special-generator sub-model for air passengers	15	*65%*
Model air passengers as home-based non-work trips	6	*26%*
Model air passengers as non-home-based non-work trips	5	*22%*
Special-generator sub-model for airport employees	5	*22%*
Model airport employees as regular journey-to-work trips	12	*52%*
Do not consider airport trips in modeling process	—	
Other	2	*9%*
Don't know	1	

Notes: a) Multiple responses allowed
b) Percent excludes "Don't know" response

AIRPORT GROUND ACCESS STUDIES IDENTIFIED BY SURVEY RESPONDENTS

Studies Involving Airport Access Mode Choice Modeling

Sponsor	Study
Atlanta Regional Commission	Regional Travel Demand Model Update
Bay Area Rapid Transit District	Oakland Airport Connector EIR/EIS
Chicago DOT/Chicago Transit Authority	Chicago Airport Express Study
Dallas/Fort Worth International Airport	Curbside Assignment Study
Dallas/Fort Worth International Airport	DFW Zonal Activity Forecasts
Federal Aviation Administration	New England Regional Airport System Plan
Federal Transit Administration	Rail Access to Honolulu International Airport
Federal Transit Administration	Rail Access to Minn.–St. Paul Int'l Airport
Federal Transit Administration	Rail Access to New York Kennedy Int'l. Airport
Federal Transit Administration	Washington–Dulles Access Study
Greater Orlando Aviation Authority	Analysis of Terminal Curbside Roadways
Hartsfield–Jackson Atlanta Int'l. Airport	Terminal Planning—Phases I–III
Lower Manhattan Development Corp.	JFK to Lower Manhattan Transit Access Study
Massachusetts Port Authority	Boston Logan AITC Environmental Assessment
Massachusetts Port Authority	Logan Express Analysis
Massachusetts Port Authority	Logan Airport Environmental Status and Planning Report
Massachusetts Port Authority	Surface Access Study of Boston Area Airports
Metro–Portland, Oregon	Airport Max (Red Line) Analysis
Miami–Dade County Transit	Airport Access Study
New York MTA/NYC Transit	LaGuardia Access Study
North Central Texas Council of Govts.	DFW Rail Access Implementation Plan
Port Authority of NY & NJ	Regional Air Service Demand Study
Port of Seattle	SEA-TAC Comprehensive Development Plan Joint Transportation Study
Sacramento Regional Transit District	Sacramento Airport Light Rail Extension Study
San José International Airport	Airport Transit Connector
Southern California Assoc. of Govts.	1998 Regional Transportation Plan
Southern California Assoc. of Govts.	2001 Regional Transportation Plan
Southern California Assoc. of Govts.	2004 Regional Transportation Plan
Southern California Assoc. of Govts.	Regional Airport Demand Model
Unspecified	O'Hare Commuter Rail Market Assessment
Privately Funded Studies	
Denver East Corridor Rail Group, LLC	Denver Airtrain Study
Resource Systems Group, Inc.	Biannual Syndicated Air Traveler Surveys
Canada	
Aéroports de Montréal	Navette du Centre-ville à l'Aéroport Montréal–Trudeau/Volet: Passagers
Greater Toronto Airports Authority	Toronto Pearson International Airport Air Rail Link Revenue and Ridership Study
United Kingdom	
BAA, Plc	Heathrow Airport Surface Access Model (2003)
BAA, Plc	Heathrow Airport Surface Access Model (2004–current)
Scottish Executive	Rail Links to Glasgow and Edinburgh Airports

High Speed Rail and Maglev Studies Involving Mode Choice Modeling

Sponsor	Study
California High-Speed Rail Authority	Bay Area/California High-Speed Rail Ridership and Revenue Forecasting Study
Florida Department of Transportation	Florida High Speed Rail Study
Maryland Department of Transportation	Baltimore to Washington Maglev Study
Pennsylvania Dept. of Transportation	Pittsburgh Maglev Study

University Research Involving Airport Access Mode Choice Modeling

University	Study
University of California, Berkeley	Planning for Improved Intermodal Connectivity at California Airports
University of Virginia	Feasibility of Offsite Terminals in Landside Access
International	
City University of Hong Kong	Ground Access Mode Choices at Hong Kong International Airport
Imperial College, London	Airport, Airline, and Access Choice in SF Bay Area
Imperial College, London	Airport, Airline, and Access Choice in Greater London
National Technical University of Athens	Access Mode Choice for Relocated Airports
National Technical University of Athens	Demand and Mode Choice in Access to Airports
National Technical University of Athens	Parking Capacity Requirements for Relocated Airports

University Research Involving Airport Ground Access Analysis

University	Study
Virginia Transportation Research Council	Evaluating Improvements in Landside Access for Airports

Other Airport Ground Access Studies

Sponsor	Study
Anchorage International Airport	Airport Roadway Traffic Analysis
E-470 Public Highway Authority	Denver E-470 (Tollroad) Airport Forecasts
Dallas Area Rapid Transit	Application of the North Central Texas Council of Governments Regional Travel Demand Model to the planning for the Northwest Corridor light rail transit line
National Aeronautics and Space Administration	Civil tilt rotor studies
Hartsfield–Jackson Atlanta Int'l. Airport	CONRAC Study
Houston Intercontinental Airport	Master Plan
I-95 Corridor Coalition	Airport Ground Access Study
Indianapolis Metropolitan Planning Organization	Intermodal Freight Study
Jacksonville Aviation Authority	Jacksonville International Airport Master Plan 2002
Los Angeles World Airports	LAX Advanced Planning
Los Angeles World Airports	LAX Master Plan EIS/EIR
Los Angeles World Airports	Ontario International Airport Master Plan—Phase 2
Metropolitan Washington Airports Authority	North Area Road Landside VISSIM Simulation
Metropolitan Washington Council of Governments	Washington/Baltimore Region Access Forecast Update
Puget Sound Regional Council	Regional Airport Ground Access Plan (2004)
Raleigh–Durham Airport Authority (with Triangle Transit Authority)	Airport Rail Link Study
Reno–Tahoe Airport Authority	Terminal Area Master Plan
Reno–Tahoe Airport Authority	Terminal Programming Study (underway)
Sacramento County Airport System	Sacramento International Airport Master Plan Update
San Diego Regional Airport Authority	San Diego International Airport Master Plan
San Diego Regional Airport Authority	San Diego Int'l. Airport Terminal 2 Expansion
San José International Airport	Terminal Area Improvement Program

Sponsor	Study
Southern California Assoc. of Govts.	2007 Regional Transportation Plan (underway)
Tampa International Airport	Airport Master Plan Updates
West Virginia Public Port Authority	Western West Virginia Regional Airport Feasibility Study
Canada	
Greater Toronto Airports Authority	Toronto Pearson International Airport New Terminal Groundside Design
Ottawa Macdonald–Cartier International Airport Authority	2006 survey of key attributes of modal choice

AIRPORT CHOICE STUDIES IDENTIFIED BY SURVEY RESPONDENTS

Studies Involving Airport Access Mode Choice Modeling

Sponsor	Study
Federal Aviation Administration	New England Regional Airport System Plan
Federal Transit Administration	Washington–Dulles Access Study
New York State Dept. of Transportation	Stewart Airport Access Analysis
Port Authority of NY & NJ	Regional Air Service Demand Study
Resource Systems Group, Inc.	Biannual Syndicated Air Traveler Surveys
Sacramento County Airport System	Sacramento International Airport Master Plan Update
San Diego Association of Governments	Maglev Study, Phase 1
Southern California Assoc. of Govts.	1998 Regional Transportation Plan
Southern California Assoc. of Govts.	2001 Regional Transportation Plan
Southern California Assoc. of Govts.	2004 Regional Transportation Plan
Southern California Assoc. of Govts.	Regional Airport Demand Model
Unspecified	High Speed Rail Access to Third Chicago Airport
Canada	
Greater Toronto Airports Authority	Air Traveller Choice in Southern Ontario

University Research Involving Airport Choice and Access Mode Modeling

University	Study
Imperial College, London	Airport, airline, and access choice in SF Bay Area
Imperial College, London	Airport, airline, and access choice in Greater London
Imperial College, London	Stated preference studies of airport choice

Other Airport Choice Studies

Sponsor	Study
Anchorage International Airport	Airport Master Plan Update 2002
Hartsfield–Jackson Atlanta Int'l. Airport	CONRAC Study
Jacksonville Aviation Authority	Jacksonville International Airport Master Plan 2002
Los Angeles World Airports	LAX Advanced Planning
Los Angeles World Airports	LAX Master Plan
Los Angeles World Airports	Remote Terminal Market Analysis for LAX
Massachusetts Port Authority	Hanscom Airport Environmental Status and Planning Report
Minnesota DOT Office of Aeronautics	State of Minnesota Leakage Study
North Central Texas Council of Govts.	DFW Rail Access Implementation Plan
Reno–Tahoe Airport Authority	2005 Catchment Area Survey
Southern California Assoc. of Govts.	2007 Regional Transportation Plan (underway)
Tampa International Airport	Air service development market studies
Tampa International Airport	International Market Study, March 2006

APPENDIX C

List of Participating Agencies

AIRPORT AUTHORITIES

State	Agency
AK	Alaska Dept. of Transportation & Public Works (Anchorage International Airport)
AR	Fort Smith Regional Airport
AZ	Albuquerque International Sunport
CA	City of San José Airport Dept. (Norman Y. Mineta San Jose International Airport)
CA	County of Orange (John Wayne Airport)
CA	Los Angeles World Airports
CA	Reno–Tahoe Airport Authority
CA	Sacramento County Airport System (Sacramento International Airport)
CA	San Francisco International Airport
CO	Denver International Airport
DC	Metropolitan Washington Airports Authority
FL	Greater Orlando Aviation Authority
FL	Jacksonville Aviation Authority
FL	Lee County Port Authority (Southwest Florida Regional Airport)
FL	Tampa International Airport
GA	Hartsfield–Jackson Atlanta International Airport
LA	Louis Armstrong New Orleans International Airport
MA	Massachusetts Port Authority (Boston Logan International Airport)
MN	Metropolitan Airports Commission (Minneapolis–St. Paul International Airport)
MO	Lambert–St. Louis International Airport
NC	Raleigh–Durham Airport Authority
NY/NJ	Port Authority of New York and New Jersey
PA	Allegheny County Airport Authority (Pittsburgh International Airport)
PA	Philadelphia International Airport
TN	Memphis–Shelby County Airport Authority (Memphis International Airport)—State Agency
TX	City of Dallas Department of Aviation (Dallas Love Field Airport)
TX	Dallas/Fort Worth International Airport
WA	Port of Seattle (Seattle–Tacoma International Airport)
WI	General Mitchell International Airport (Milwaukee)

Canada

Quebec	Aéroports de Montréal
Ontario	Greater Toronto Airports Authority
Ontario	Ottawa Macdonald–Cartier International Airport

METROPOLITAN PLANNING ORGANIZATIONS

State	Agency
CA	Sacramento Area Council of Governments
CA	Southern California Association of Governments (Los Angeles region)
CT	Capitol Region Council of Governments (Hartford)
DC	Metropolitan Washington Council of Governments
FL	First Coast Metropolitan Planning Organization (Jacksonville)

State	Agency
FL	Hillsborough County Metropolitan Planning Organization (Tampa)
FL	Metroplan Orlando
GA	Atlanta Regional Commission
HI	Oahu Metropolitan Planning Organization (Honolulu)
IL	Chicago Metropolitan Agency for Planning
IN	Indianapolis Metropolitan Planning Organization
KY	Kentuckiana Regional Planning and Development Agency (Louisville)
MA	Central Transportation Planning Staff (Boston)
MD	Baltimore Metropolitan Council
MN	Metropolitan Council of the Twin Cities (Minneapolis–St. Paul)
NV	Regional Transportation Commission of Southern Nevada (Las Vegas)
NY	New York Metropolitan Transportation Council
OH	Northeast Ohio Areawide Coordinating Agency (Cleveland)—State Agency
OH	Ohio–Kentucky–Indiana Regional Council of Governments (Cincinnati)
OR	Metro (Portland)
TX	Houston–Galveston Area Council
TX	North Central Texas Council of Governments (Dallas/Fort Worth)
VA	Virginia Department of Transportation (travel modeling for MPOs in Virginia)
WA	Puget Sound Regional Council (Seattle)

AIRPORT/TRANSPORTATION CONSULTING FIRMS

State	Organization
CA	Dowling Associates, Inc. (Oakland)
CA	Mark Bradley Research and Consulting (Santa Barbara)
CA	PB Consult (San Francisco)
CA	Velocity Group (San Francisco)
CO	PRT Consulting, Inc. (Franktown)
MA	Cambridge Systematics, Inc. (Cambridge)
MA	MarketSense Consulting, LLC (Charlestown)
MA	SH&E, Inc. (Cambridge)
MD	Vanesse Hangen Brustlin (Silver Spring)
NY	Aviation Consulting (New York)
NY	Earth Tech (New York)
PA	GRA, Incorporated (Jenkintown)
SC	Wilber Smith Associates (Columbia)
TX	DMJM Aviation (Fort Worth)
TX	TransSolutions, LLC (Fort Worth)
VA	AECOM Consult, Inc. (Arlington)
VA	HNTB Corporation (Alexandria)
VA	Larry Kiernan, Consultant (Reston)
VA	Ricondo & Associates (Alexandria)
VT	Resource Systems Group, Inc. (White River Junction)—State Organization
WA	HDR Engineering, Inc. (Bellevue)
WA	URS Corporation (Seattle)

International

Australia	Sinclair Knight Merz (Armadale, Victoria)

RESEARCH ORGANIZATIONS

State	Organization
CA	University of California at Berkeley
MI	Michigan Tech University (Houghton)
VA	University of Virginia (Charlottesville)
VA	Virginia Transportation Research Council (Charlottesville)

International

Greece	National Technical University of Athens
H.K.	City University of Hong Kong
U.K.	Imperial College (London)

STATE AND FEDERAL GOVERNMENT

State	Agency
AZ	Arizona Department of Transportation, Aeronautics Division (Phoenix)
CA	California Department of Transportation, Division of Aeronautics (Sacramento)
FL	Florida Department of Transportation, Aviation Office (Tallahassee)
IA	Iowa Department of Transportation, Office of Aviation (Ames)
KY	Kentucky Department of Aviation (Frankfort)
MN	Minnesota Department of Transportation, Office of Aeronautics (St. Paul)
MS	Mississippi Department of Transportation, Aeronautics Division (Jackson)
ND	North Dakota Aeronautics Commission (Bismarck)
NE	Nebraska Department of Aeronautics (Lincoln)
NJ	New Jersey Department of Transportation, Division of Aeronautics (Trenton)—State Agency
NY	New York State Department of Transportation, Aviation Services Bureau (Albany)
OH	Ohio Department of Transportation, Office of Aviation (Columbus)
OK	Oklahoma Aeronautics Commission
OR	Oregon Department of Aviation (Salem)
TX	Texas Department of Transportation, Aviation Division (Austin)
WA	Washington State Department of Transportation (Arlington)

Federal

DC	Federal Aviation Administration
DC	Federal Transit Administration
MA	U.S. Department of Transportation, Volpe National Transportation Systems Center

Abbreviations used without definitions in TRB publications:

AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	Air Transport Association
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation

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